UNIVERSITY OF SZEGED
FACULTY OF ECONOMICS AND BUSINESS ADMINISTRATION
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**Time-Variation in the Pricing of Country
Fundamentals in Sovereign Credit Spreads**

Doctoral Thesis of

Zalán Kocsis

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Supervisor:

dr. habil. Gábor Dávid Kiss, PhD

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Abstract

An expanding strand of macro-finance investigates whether the relationship between asset prices and their fundamental determinants are stable or vary through time. Empirical results in the sovereign credit risk literature unanimously support time-variation, however the roots of these findings received less attention.

The theoretical part of the thesis contributes a model of sovereign credit risk that extends the framework of [Eaton and Gersovitz \(1981\)](#) to incorporate aspects of the external share of government debt, funding liquidity crises and political economy preferences. The model calls attention to several variable interactions that may explain findings of time-variant effects in reduced-form models.

The empirical part first shows that the log-linear functional link between sovereign credit spreads and ratings is more robust than the linear specification used in much of current empirical work. However, even in the log spreads specification, fundamental effects are found to be time-varying. The role of fundamentals overall seem to have declined in the eurozone sovereign crisis, even though the role of the debt ratio has increased exactly in this period. This lends support to the wake-up call hypothesis regarding debt repricing in spreads. This repricing was of a quantitatively important magnitude.

Executive summary

The thesis relates to the subject matter of sovereign credit risk determinants. A substantial part of government bond yields and hence interest payment on public debt is related to sovereign risk, the risk of non-payment by the sovereign (government) issuer. Understanding the determinants of this risk and thus a cost of public debt is therefore important for policymakers and taxpayers. For investors in bond and credit derivatives markets the determinants of sovereign risk are important to understand so that they can bring optimal investment decisions and properly manage risk.

The current study enters into a decade-long discussion of **how country fundamentals affect sovereign credit risk and whether such effects can be considered stable over time.** The related literature documents that the sovereign risk – fundamentals relationship contains structural breaks on time samples that include the global financial and eurozone sovereign crisis. However, different authors found different variables to have had such changed effects. An often found conclusion of studies evaluating the eurozone experiences is that government debt has become more important in pricing. Theoretical justification for findings relate to imperfect information and behavioral biases leading to a 'wake-up call' effect or jumps between multiple equilibria due to various possible reasons. An alternative, econometric, explanation for estimated time-variation in effects is that empirical models are misspecified.

The thesis aims to research the background for these findings.

As a first tool it investigates the issue of possible non-linear and interaction effects of fundamentals in a simple, stylized theoretical model – Part II of the thesis. The model builds on the classic endowment economy framework of [Eaton and Gersovitz \(1981\)](#), where default is the result of a cost-benefit analysis of a rational government. The model is highly stylized as it uses a nearly static, nearly deterministic framework, where investors are passive and government decisions other than the one on default are restricted. With these simplifications, the model can be analytically solved with extensions into several directions that capture important aspects missing from other models, such as domestic bondholdings, size of the financial sector, political economy aspects and fundamentals related to possibility of liquidity crises (reserves, foreign currency debt).

A comparative statics approach is used to study the effects of fundamental factors on sovereign credit risk within the model. The analysis assesses how altering the values of fundamental parameters within ranges observed in the data (a large historical data set is compiled for the thesis comprising 125 countries in the 1960-2017 period) affect the strategic value of default (SDV), the relative value of default over repayment. SDV effects are calculated for each fundamental parameter at various levels to identify non-linearities and at various values of other fundamentals to identify interaction effects. **The model suggests several important**

interactions, but non-linearities were less of an issue.

The most interesting observation relates to the effect of the debt ratio. In contrast to an uncontested result in the theoretical literature that the debt ratio increases credit risk, I show both analytically and numerically (calibrating parameters to emerging market and developed country data) that the sign of the debt ratio effect is ambiguous and depends on several other factors. Higher debt decreases spreads when trend growth is high compared to real interest rates, but increases it when trend growth is lower. Higher debt decreases spreads when debt is domestic and the probability and depth of a default-triggered crisis is large. Higher debt increases spreads when debt is external or when it is foreign-currency denominated and there is a large probability of a funding liquidity crisis.

As mentioned, there are important limitations of the model, regarding the passivity of investors, restricted decisions of government, limited dynamics and stochastics. In the Appendix I present a model that endogenizes interest rates, allows gradual changes in the debt ratio and adds a few more dynamic and stochastic elements to the model and still leads to very similar results.

The empirical part of the thesis (Part III) begins with a chapter that assesses various empirical properties of ratings and sovereign credit spreads.

As a resource for later empirical work in the thesis – and as a potential contribution to the empirical research community – **it shows that logarithmic spreads have a robust, linear functional link with linearized ratings** (and fundamentals affecting SDV linearly). The first step of this derivation is demonstrating a strong empirical link of a logistic form between ratings and default probability (linearity with default log-odds). The linear link between ratings and log spreads follows from spreads being log-linearly related to the log-odds of default. With added assumptions on the dynamics of SDV, I derive linearity between SDV, its linear fundamental factors and log spreads. **Due to the lagged nature of ratings, the uncovered empirical link with log spreads are better captured in the cross-section than in the time series implying more robust models in levels than in (quasi-)differenced forms.**

The preliminary empirical work also uncovers other properties of spreads, which suggest that **simple reduced form models standard in the empirical literature will be more robust when using spreads in logarithmic rather than linear, nominal form.** In case of nominal spreads both the volatility and sensitivity to global shocks significantly vary in time and across countries and these attributes are also strongly related to the level of spreads. By contrast, the volatility of log spreads is largely unrelated to log spread levels and log spreads also react more evenly to common shocks. Simple models that do not address a complex volatility and factor structure will therefore be more appropriate when using log spreads.

The empirical literature is versatile in the model specifications used to study the relationship of spreads and fundamentals and there are several possible tests available to use for assessing structural breaks. Moreover the small sample size, correlation and noise in the data makes it even less straightforward, which specification and testing procedure should be chosen. To aid

this decision, an extensive Monte Carlo exercise is carried out that matches moments of the data and confirms that in the current, small sample context F-tests are the appropriate tool to use and it also pins down the appropriate model specifications (levels specification instead of quasi-differenced forms, models with period effects and without cross section effects) out of the many possibilities available and used in the empirical literature.

The empirical analysis confirms time-variation of effects of sovereign ratings on both linear and logarithmic sovereign credit spreads. **It also confirms that the variance share explained by ratings changed over time.** The results are robust to inclusion of various sets of macroeconomic variables and to using various model specifications within the set proposed by the Monte Carlo exercise.

There are multiple reasons for the observed time-variation. First, the sensitivity of bond spreads and CDS spreads to global shocks varies across credit ratings, shifting the cross-section slope of spreads to ratings. Risky sovereigns experience larger spread increases when global risk aversion becomes stronger, which raises the sensitivity of spreads to ratings in the cross section. The logarithmic transformation of spreads successfully mitigates, but does not eliminate the heterogeneity, as low-risk issuers tend to experience a somewhat larger effect due to global shocks on their spreads in percentage terms.

Another factor for time-varying sensitivity of spreads to ratings, evident in the sovereign crisis, was the consequence of rating agency lagged reactions in marking down the credit quality of risky developed country issuers. The financial crisis triggered a large fiscal reaction in developed countries due to which the market has increased spreads in this low-rating segment. This led to a drop of the sensitivity of log spreads to ratings in the cross-section and it substantially lowered the variance share of the cross-section of log spreads that ratings could explain. As rating agencies eventually caught up with the market, the sensitivity of log spreads to ratings (and the variance share explained by ratings) has increased back.

The last part of the thesis turns to the wake-up call hypothesis (Goldstein, 1998) regarding the debt ratio in determining sovereign spreads. The results support the hypothesis: log spreads have become more sensitive to the debt ratio mainly in developed countries and the eurozone, but also in emerging markets. Interestingly, rating agencies - although with a significant lag compared to the market - appear to also have given larger weight to the debt ratio after the eurozone sovereign crisis. In fact, this lagged reaction of agencies and thus the disparity of how the market and rating agencies evaluated the effect of debt on spreads could partly explain the decline of rating explanatory power in spreads during the sovereign crisis. **Relating to the theoretical model in the thesis, the changes in debt effect appear to be channeled through the external debt component. This may on one hand show perceptions of increased real interest rates relative to trend growth. On the other hand it may indicate an increased role of funding liquidity aspects in credit risk** as external debt may capture some of this effect in the eurozone, where foreign currency debt is not a useful proxy.

CHAPTER 1

Introduction

This doctoral thesis seeks to improve our understanding about how country fundamentals relate to the pricing of sovereign credit risk, the risk that the government representing the sovereign will default on public debt obligations. Within this larger topic, it more specifically deals with the issue of time-variation and explores whether the relationship between fundamentals and sovereign credit spreads is stable in time.

1.1 Motivation

Sovereign credit spreads are the yield differentials that sovereign (government) borrowers have to pay for investors over the risk-free rate to compensate them for the additional risk of holding a risky bond. Sovereign credit spreads also manifest in derivatives markets in sovereign CDS premia. Both bond spreads and CDS spreads have two major components: (i) the 'actuarial' default risk component in the terminology of [O'Kane \(2011\)](#), which is the compensation for the expected loss due to the risk of non-payment, and (ii) a risk premium component that is charged for the uncertainty and future variation in the credit spread (due to both the actuarial component and the risk premium itself).

Understanding the drivers of sovereign credit spreads is important for policymakers, taxpayers and investors alike. Policymakers and taxpayers are interested in the drivers of sovereign spreads, because public debt service costs (a significant part of government expenditures) depend on sovereign credit spreads. Different policy actions are optimal when the path of future spreads is more/less uncertain, when there is a high/low probability of a large increase in spreads. Knowing which country fundamentals determine credit spreads (and how important country fundamentals are compared to global factors) facilitates choosing policies that lowers the cost of servicing public debt.

Investors are interested in the drivers of credit spreads, because spreads directly influence the market value of bonds in secondary markets. An increase in credit spreads causes a valuation loss for bond investors, which is realized either if bonds are sold prior to maturity or in the case that the government defaults on debt. Similarly, sellers of CDS protection incur valuation losses on their position as spreads increase. Furthermore, variation and uncertainty regarding the bond price and the future value of the CDS position requires holding costly capital or cash on margin accounts. For investors, therefore a model of the data generating process of spreads is useful as it translates investor predictions about economic fundamentals into credit spreads and this is necessary for active trading to choose investment strategy, for risk management to develop proper stress scenarios, and for portfolio management to gauge diversification benefits.

However, there is substantial uncertainty surrounding predictions about future credit spreads. Both the underlying factors are difficult to forecast and the data generating process of credit spreads is difficult to pin down. This latter aspect, what factors determine credit spreads and how, has been the subject of an extensive literature on sovereign credit risk. Theoretical considerations, as discussed in the thesis, allow many factors (fundamentals and non-fundamentals) to influence pricing, but empirical estimation of partial effects is hindered by a small number of independent observations, the fact that relevant factors are correlated and that many factors have only lagged and noisy proxies available. Therefore it is not possible to arrive to a single-best model of sovereign credit risk determination.

It is obvious from encounters of market participants (e.g. traders, portfolio managers regularly express their views in media appearances) that they have heterogeneous views about both the future of the economy (fundamentals) and about which fundamentals they consider to be important in shaping prices in the market. Although theory and empirical data point out general possibilities as to how credit spreads may be determined, they leave ample room for market participants to choose different models and to compete with each other in this respect, which then, reinforces model uncertainty. In particular, investors are interested in successful forecasting not only how the economy will evolve, but how the 'true' model linking the economy to credit spreads, i.e. how other investors will model this link, will evolve.

This view of the market leads up to the subject matter of the thesis, time-variation in the relationship between fundamentals and sovereign credit spreads. Are the empirical data really consistent with changing weights of fundamentals in credit spread determination over time? Or is the commonly found time-variation the result of inadequate data and/or model misspecification? Even if a true time-invariant model existed, the data difficulties highlighted above (lagged, noisy, correlated proxies) or a misspecified model (omitted relevant variables, variable interactions and wrong functional form) could lead to an erroneous rejection of time-invariant effects.

Although answering the above questions with certainty is not possible due to data limitations, the goal of the thesis is to provide a proper theoretical elaboration of possible omitted factors, elaboration and checks of possible functional form misspecification, and an empirical procedure that an appropriate testing method, which is adequate for particularities of the data set and application at hand. This allows a contribution to the extant literature in providing a more refined answer to the above questions and explanations for some of the common findings on the subject matter so far. Such a contribution, as argued above, is also important outside of the research community, for both debtors (policymakers, taxpayers) and investors.

1.2 Structure of the thesis

The main text of the thesis is structured as follows.

Part I provides an overview of the relationship between sovereign credit risk and fundamen-

tals as we currently understand from both theory and the empirical literature.

Chapter 2 begins with a brief account of standard macroeconomic and political economy theories of fiscal policy goals and fiscal policy tools, including debt finance. The chapter then reviews the theoretical literature of sovereign credit risk turning first to the willingness to repay aspect to defaults. This aspect of sovereign credit risk assumes that governments decide on default due to a cost-benefit analysis and it is the aspect that distinguishes it from corporate credit risk. Other aspects of sovereign credit risk in the theoretical literature are then assessed including the ability to repay (debt sustainability and funding liquidity issues) and political economy considerations.

Chapter 3 discusses the key properties of the common indicators of sovereign credit risk (credit ratings, bond spreads and CDS spreads) identified by the literature. All three indicators are noisy proxies of sovereign risk. Credit ratings change gradually and reports by agencies themselves explain the reason for why ratings cannot be timely. Bond spreads and CDS spreads appear to be more timely indicators, but they have a substantial risk premium component that reflects factors rooted outside of domestic fundamentals. This risk premium has empirically been found to display strong comovement across countries.

Chapter 4 turns to an examination of the empirical literature that investigates the observed relationship between the three sovereign credit risk indicators and domestic fundamentals. The review evaluates the results of more than 70 empirical papers relying primarily on statistical tools. The meta-analysis of this literature reveals a lack of robustness in the link between sovereign credit risk indicators and various fundamentals and it investigates the factors that explain variation in reported results. The final section of Chapter 4 reviews the segment of the empirical literature that specifically relates to time-variation of fundamental effects in the determination of sovereign credit risk proxies, sovereign credit spreads and ratings.

Part II and Part III present my additions to this literature.

Part II of the thesis proposes a new theoretical model of sovereign credit risk. The model follows the cost-benefit framework of [Eaton and Gersovitz \(1981\)](#), but adds three non-standard elements. First, Model I in Chapter 5 distinguishes externally and domestically held debt and it argues that the two affect the willingness to pay aspects of credit risk in different ways. Second, Model I also adds two political economy elements, a general bias toward debt finance and the political economy stance of government toward repayment, that are claimed to be important determinants of sovereign risk. Third, Model II in Chapter 6 adds funding liquidity and the ability to pay aspects of default. These elements, though non-standard in this framework, have each been elaborated separately by different segments of the literature and are understood by the research community to be important drivers of sovereign risk. The main contribution of this modelling exercise is bringing these factors together under one umbrella. This permits studying important interactions between these aspects, which is overlooked by partial models.

Part II ends with a brief chapter, Chapter 7, that states the main hypotheses regarding time-variation of fundamentals priced in sovereign credit spreads.

Part III constitutes the empirical contributions of the thesis. A key task to resolve is selecting the appropriate model specifications and estimation techniques to use from the plethora of models that the empirical literature has proposed.

In Chapter 8 I begin by elaborating the empirical regularities of the key variables of the data set, sovereign credit ratings and sovereign credit spreads. I show how both of these measures relate to the probability of default itself and link the two measures based on these results. In particular, the logarithmic spread - linearized rating specifications seem to be a robust characterization of this relationship.

Chapter 9 presents methodological tools used in the literature to assess time-variation and evaluates their applicability to the specific data set and problem at hand. It also proposes general model specifications that encompass many of the estimated models reviewed in the empirical literature section. The chapter conducts an extensive Monte Carlo exercise that studies how various tests of parameter stability perform in the context of variables characterized by the empirical regularities uncovered in Chapter 8 and using various empirical model specifications of the existing empirical literature. Chapter 8 and 9 thus reduces the set of specifications to a few that are expected to provide a good fit to true coefficients and low (Type I and Type II) errors of coefficient stability tests.

Chapter 10 uses these specifications and carries out hypotheses tests. A battery of specifications (out of the ones that were found to be appropriate earlier) are used to arrive to robust results. The chapter also investigates some possible reasons for the findings.

PART I

Concepts and literature review

CHAPTER 2

Sovereign risk and fundamentals: theory

This Chapter summarizes the theoretical literature on sovereign credit risk and discusses how country fundamentals relate to sovereign credit risk in theory. The goal of the chapter is also to introduce and define main concepts used throughout the thesis and to give an overview not only on how fundamentals and sovereign risk are related but to peer into the interactions of fundamentals themselves relevant for sovereign risk. The interrelationship of fundamentals and the several (context-dependent) channels of effects on sovereign risk already suggests that the effect of fundamentals on sovereign risk varies through time.

2.1 Theories of fiscal policy and public debt

Sovereign credit risk is fundamentally connected to theories of fiscal policy and public debt. The trivial reason is that without public debt there is no sovereign credit risk and fiscal policy is responsible for the decision to issue debt. A more involved reason is that both the government decision about whether to issue debt and investor decision about whether to buy public debt are related to deliberations about the possibility of sovereign default. A benevolent government may consider the possibility of defaulting in future recessions which may be an additional tool to smooth the business cycle. An opportunistic government may consider the benefits of running up debt and then defaulting.

Rational investors would need to take these considerations into account. They would not buy sovereign debt securities without being compensated for the risk of default.¹ By standard arguments in finance theory, investors also need to take into account how the probability of default is correlated with their own marginal utility of consumption (discussed in more detail in Chapter 3).

Therefore I begin by a brief account of the motivations of fiscal policy and in particular of issuing public debt.

The government has the following basic functions regarding the economy:² (i) setting up and maintaining the institutional framework that facilitates economic cooperation between economic agents (e.g. rule of law, protection of private property), (ii) correcting market failures where the

¹If there were no costs to defaulting, then governments would not repay debt obligations, but then market issuance of debt would also be impossible. This places investors and governments into a game theoretic relationship, where each side needs to consider probable actions/considerations of the other side. Although 'gunboat diplomacy' (threatening by wars) is not relevant anymore, coordination via other sanctions (reduction in trade or confiscation of international assets) are discussed in the literature. Defaults may also entail negative consequences on political and economic reputation, and various economic and financial costs.

²Economic functions of the government can be categorized several ways. Here I rely on the categorization in Kovács (2010).

market would over- or underinvest: in particular, running the public sector that provides public services and allocates public goods to society, (iii) redistribution of wealth and income between groups of society, (iv) macroeconomic stabilization: smoothing business cycles by increasing spending in downturns and limiting spending in economic booms (some of the fiscal policy tools, e.g. income or consumption taxes and unemployment benefits are automatic stabilizers that cause countercyclical fluctuation in the fiscal balance).

There is not much debate about the necessity of the first function and this function does not carry costs that materially contribute to fiscal imbalances and running up debt.

Regarding the second and third functions, the field of comparative economics finds large disparities across countries and regions, which are mainly rooted in historical-cultural differences. Most European countries have public sectors that support large social safety nets and provide more public goods than what is characteristic in other regions. The size of the state and the role of income redistribution is smaller in emerging markets, in particular, Latin American economies. There have been large differences about the role that the state has played in the economy regarding production. In many Asian countries and in socialist planned economies state owned companies were important, whereas in US and Western Europe government spending mostly consisted of government consumption, the role for government investments was limited.³

These choices by themselves need not influence budget deficits and hence debt levels, because larger spending levels could be balanced by larger tax revenues. Therefore these government functions largely lie outside of the scope of the thesis, although the historical-cultural traits that likely underlie such regional differences in government activity are also important determinants for household and government behavioral parameters that impact decision on debt accumulation.⁴

The fourth government function, the role for stabilization policies has been a key discussion point in the history of economic thought and has significant implications for fiscal deficits, although not the level of government debt. If fiscal policy is effective in smoothing the business cycle, then the government can help households smooth their consumption by running countercyclical fiscal policy and (assuming diminishing marginal utility of consumption) increasing their overall welfare.

Fluctuations in the fiscal balance is related to the issue of debt vs tax finance of government expenditures. Running a budget deficit at some point assumes that government tax revenues do not cover expenditures (government spending and debt service), in which case government debt will rise.

Loosely following the notation in [Romer \(2006\)](#), debt growth equals the sum of the primary

³Comparative analysis shows that there are vast institutional differences even within the enlarged European Union ([Farkas, 2016](#)).

⁴In Appendix [C.1](#) I propose a model of endogenous fiscal policy, in which household time preference (subjective discounting) is a key input that is probably related to cultural traits and which has implications regarding both the size of the public sector and deficit bias.

deficit and debt service on existing debt:

$$\Delta D_t = (G_t - T_t) + r_t D_{t-1} = -PB_t + r_t D_{t-1}, \quad (2.1)$$

where G_t , T_t , PB_t , r_t are government expenditures, taxes (net of transfers), the primary balance and real interest rate in time period t , respectively. D_t denotes (net) debt at the end of time period t and Δ is the first difference operator.⁵

Usually it is assumed that the government has to balance the budget on the long-run, because rational investors would otherwise not hold government bonds.⁶ Then, primary surpluses have to be greater than or equal to initial debt:

$$\sum_{t=0}^{\infty} e^{-\delta_t} PB_t \geq D_0, \quad (2.2)$$

where δ_t is an appropriate discount factor.⁷ Equality could be assumed for an optimizing government.

Can fiscal policy influence economic output?

The plausibility of countercyclical fiscal policy smoothing income fluctuations hinges on the assumption that fiscal policy can effectively influence economic growth at least on the short-term. Classical strands of economic theory have been sceptical, whereas Keynesian strands and other theories that allow various market inefficiencies or behavioral biases supported a positive answer.

Standard textbook economics⁸ tells us that when economic agents can be assumed to be largely rational, knowledgeable about how the economy works, markets are close to being efficient and economic output is close to its maximum potential, then expansionary fiscal policy does not have a significant effect on output, because households save their extra disposable income reducing consumption demand or because government spending crowds out private investment.

This could work through expectations consistent with classical arguments of (rational) household optimization in a permanent income hypothesis framework. Households will rationally expect that (due to the government budget constraint) the consequence of a fiscal expansion is a

⁵ Assuming only one type of real interest rate, r_t , which is constant within the indexed time interval and can be thought of as the average real yield paid on outstanding debt.

⁶ Blanchard and Weil (2001) discuss the possibility of government Ponzi finance (forever rolling over debt and never repaying). In a deterministic setting with real growth rates higher than real interest rates, this is a possibility. In stochastic settings there are conditions under which Ponzi finance is possible, but the positivity of the difference between real growth rates and real interest rates is neither necessary nor sufficient a condition.

⁷ Bohn (1995) argues that covariance between marginal utility and the fiscal deficit has to be taken into account. Using a discount factor such as historical or current risk free rates are erroneous if fiscal policy is assumed to dynamically adjust to changes in interest rates.

⁸ In the following discussion I mainly rely on the textbooks of Romer (2006) and Mankiw (2012), as well as Gale and Orszag (2002) and Molnár et al. (2017).

future fiscal contraction and that their permanent income is unaffected by current policy. In order to avoid fluctuations in consumption, households save the extra disposable income (buying government bonds), so that later, when taxes are raised and disposable income falls, they can use these savings to raise consumption. In particular, only government expenditures (which reduces savings) enters the household budget constraint, neither taxes nor debt is present in either the household utility function or the budget constraint. This shows that whether government spending is financed by current taxes (balanced budget) or debt (fiscal expansion) is immaterial for household consumption decisions, the Ricardian equivalence result (Barro, 1974).

An influential paper by Barro (1979) argues that even if Ricardian equivalence held, government could still have a motivation to issue debt and run a countercyclical fiscal policy if taxes had distortionary effects. In this model the increase in the tax to income ratio leads to increasing costs. In this case, government is interested in avoiding fluctuations in the tax rate and since government expenditures fluctuate due to the business cycle, it is valuable for government to temporarily issue debt to smooth the tax rate process.

Ricardian equivalence may be an appropriate description when classical assumptions hold. When the permanent income hypothesis fails, Ricardian equivalence fails as well.⁹ However, even if Ricardian equivalence failed the effect of a fiscal expansion on output could be significantly reduced through an increase in the real interest rate. On one hand, the increasing fiscal deficit must be financed by either domestic or external savings. In a closed economy the government competes with domestic private investors for domestic funds, which drives up the interest rate. Higher interest rates reduce private investments, which may counteract the positive demand of government spending and may negatively affect capital stock and thus long-term growth. On the other hand, in both a closed and an open economy, an increased government debt level raises the interest rate premium on government debt, which may spill over to private market interest rates.

The extent of these effects depends primarily on the elasticities of savings and investments to interest rates. In the closed economy, if households have a high marginal propensity to consume (for instance households are credit constrained and they consider having enough savings), then interest rates have to rise more to convince households to save enough for government spending. On the other hand, if private investments are sensitive to interest rates (investments become unprofitable at marginally higher interest rates), then government spending crowds out private investments without much increase in either interest rates or household savings. Thus fiscal policy is more effective if the private sector is less willing to consume and more willing to invest.¹⁰

⁹Mankiw (2012) mentions two possibilities for why Ricardian equivalence may fail. First, households may exhibit myopia: not being fully rational when planning consumption on the long-term or otherwise believing that fiscal expansion does somehow increase permanent income. This idea of 'fiscal illusion' has a long history in economic theory with David Ricardo himself advocating it (O'Driscoll Jr, 1977). Second, households may initially be credit constrained, in which case their initial consumption decision is determined by actual instead of permanent income. A fiscal expansion in these cases increases consumption.

¹⁰Gale and Orszag (2002) estimated on US data that a worsening of the fiscal balance by 1 percentage point

In a small open economy with an open capital account (Mundell-Fleming model), an increase in fiscal spending raises real interest rates only through the risk premium component (the increase of which is subject to risk aversion), because the riskless interest rate is determined externally. Fiscal expansion is then financed by an inflow of foreign capital. In the flexible exchange rate regime, the inflow causes the exchange rate to appreciate and a resulting deterioration in external trade reduces or eliminates the income effect of fiscal policy. In a fixed exchange rate regime, however, the capital inflow will cause international reserves at the central bank to expand.¹¹ Note, however, that after the initial capital inflow and government debt issuance, subsequent debt servicing is consistent with capital outflows. This, on one hand, reduces risk and risk premia, but contributes to a sustained depreciating pressure on the exchange rate.

These factors together determine whether fiscal expansions lead to (short-term) increases in economic output.

On the longer run, most economists believe that prices adjust and economic output is only determined by the endowment of production inputs: such as labor (population growth and activity), human capital, physical capital. Therefore the affect of government policy depends on the impact on these factors.

The empirical literature came up with wide ranges of estimates for the fiscal multiplier, the extent to which government spending or tax reductions increase output. Reviewing the literature, [Ramey \(2016\)](#) found most estimates of the spending multiplier to be in the range of 0.6-1.5, whereas tax multipliers were generally somewhat larger in absolute value (see Tables 4.1 and 4.4 in that study). [Dupor and Guerrero \(2017\)](#) reported US defense spending multipliers to be lower, around 0-0.5, and argued that previous estimates were larger, because of the Korean War episode. Based on Bayesian VAR estimates that better take into account fiscal foresight, [Ellahie and Ricco \(2017\)](#) found that the fiscal multiplier depended on the type of shocks with government consumption having a 0.7 multiplier, whereas government investments having multipliers well above 1.

[Eggertsson and Krugman \(2012\)](#) discuss a model economy with two types of households differing in their subjective discount rates. Impatient households borrow from patient households but may experience periods when their credit is rationed. The ensuing deleveraging causes aggregate output to fall, because patient households cannot be convinced to consume more. The output drop is particularly acute when nominal interest rates are near the zero lower bound. In these cases fiscal policy can temporarily boost demand to smooth aggregate spending and it will have large multipliers. According to this model, the multiplier will be larger the closer the economy is to the zero lower bound and the larger is the share of impatient-deleveraging households. [Eggertsson and Mehrotra \(2014\)](#) proposes a model, in which the debt deleveraging shock has permanent effects.

increased interest rates by around 0.5 to 1 percentage points.

¹¹Let us assume that created domestic liquidity is sterilized so that prices are not affected.

Based on a model similar to [Eggertsson and Krugman \(2012\)](#), [Pragidis, Tsintzos and Plakandaras \(2017\)](#) find that the fiscal multiplier is state-dependent: it is smaller for expansionary than for contractionary policies. They find the multiplier is larger when long-run inflation is at zero and when financial conditions are stressed. However, recent papers cast doubt on some of these results: [Ramey and Zubairy \(2018\)](#) provides contrasting evidence about differences in fiscal multipliers in good and bad times, whereas [Hills and Nakata \(2018\)](#) claims that taking shadow rates into account would lower spending multiplier estimates in periods when interest rates were below zero.

The general conclusion from both theory and empirical research is that fiscal policy appears to be able to increase output with a fiscal expansion on the short run, but the extent of the effect is uncertain and depends both on the nature of the surrounding economic environment and the concrete policy measures taken by the government.

Fiscal policy and the business cycle

Empirical evidence on whether or not governments do act countercyclically and smooth business cycle fluctuations has been mixed. [Raess and Pontusson \(2015\)](#) show that in case of developed (OECD) countries fiscal policy was mostly countercyclical. On a different sample, however, [Roubini and Sachs \(1989\)](#) find evidence contrasting tax smoothing and rather favored political explanations as being more plausible for debt dynamics. [Kaminsky, Reinhart and Végh \(2004\)](#) report an acyclical reaction function for developed countries.

The general finding in case of emerging markets is that fiscal policy has been procyclical. [Kaminsky, Reinhart and Végh \(2004\)](#) bring empirical evidence that in emerging markets government spending increases and inflation tax rates decline in economic upturns. The authors also report that capital inflows tend to also increase in upturns, while these countries experience capital outflows in recessions. On this note, [Aguilar and Gopinath \(2007\)](#) claim that a key difference between emerging markets and developed countries is that economic shocks in emerging market are much more persistent, thus rational households and governments are less inclined to smooth these shocks. This causes consumption to be more volatile than income in emerging markets and current account fluctuations to be procyclical.

Procyclicality in the current account could also be a consequence of financial shocks, as external demand for emerging market assets usually falls during global downturns. In these cases capital flight increases emerging market interest rates and puts depreciating pressure on currencies (e.g. [Baksa and Konya, 2017](#)). Emerging markets may also face constraints that prevent them from running stabilization policies. For instance, monetary policy could be forced to keep interest rates elevated to prevent an exchange rate depreciation (e.g. [Gereben, Karvalits and Kocsis, 2011](#); [Benczur and Konya, 2016](#)) and high risk premia may act as a deterrent for emerging market governments to run up debt during downturns. [Neumeier and Perri \(2005\)](#) point out empirical evidence of a strong negative relationship between real interest rates (derived from credit spreads) and the business cycle in emerging markets.

Political economy and other considerations for fiscal policy and debt

[Alesina and Tabellini \(2005\)](#) argue that the procyclicality seen in emerging market fiscal policy as opposed to developed countries rather stems from differences in the utility functions of emerging market and developed country politicians. Namely, developed country governments can be assumed to be benevolent (acting to increase private sector utility), whereas in emerging markets politicians follow a rent-seeking behavior. Since more rent-seeking opportunities arise in good times, government spending with debt finance rises and this may explain procyclicality of fiscal policy.

Fluctuations in fiscal policy conduct may also arise for different non-business-cycle reasons. Several authors show the existence of political cycles: fiscal deficits tend to rise before and fall after elections (see [Gaspar, Gupta and Mulas-Granados, 2017](#), and references therein). Other papers find that partisanship, ideology of the party that runs the government on the left-right political scale, causes differences in fiscal deficits (for instance, [Raess and Pontusson, 2015](#); [Müller, Storesletten and Zilibotti, 2016](#); [Scholl, 2017](#)).

Political economy and behavioral theories appear to be better in explaining consistent fiscal deficits and large debt ratios that are observed worldwide. The reasoning by [Buchanan and Wagner \(1977\)](#) is that the impacts of current policy is immediately and directly felt, whereas the effects of future policies are indirect (the already mentioned myopia and fiscal illusion). Policymakers are therefore inclined to run fiscal deficits, because the electorate gives larger weight to the benefits of current consumption compared to future expected costs.

However, a string of political economy papers ([Alesina et al., 1998](#); [Eslava, 2011](#); [Brender and Drazen, 2008](#)) provide empirical evidence that counters the intuition on fiscal illusion and the electoral payoff to political budget cycles (see a detailed discussions in [Alesina and Passalacqua, 2016](#)). Based on these empirical studies voters seem to be much more fiscally conservative than conventional wisdom suggests, even punishing governments that engage in deficit spending before elections. The validity of these empirical methods are however debatable on two accounts. On one hand potential reverse causality may be relevant: already popular governments are more likely to engage in fiscal adjustments and still win elections. On the other hand initial conditions may also influence results, i.e. whether the elections and fiscal adjustments are set in a crisis environment or an economic boom (see discussion and comments of Barry Eichengreen and Maurice Obstfeld in [Alesina et al., 1998](#), pp. 242-260).

Political rivalry and political instability has been a key factor in persistent deficits. [Alesina and Tabellini \(1990\)](#) suggest that altering views about government spending by two political factions could lead the incumbent using debt finance to commit policy towards its own goals, so that in case of losing the next elections, the actions of the next government will be constrained by debt servicing. This is similar to studies of [Amador \(2003\)](#) and [Cuadra and Saprizza \(2008\)](#), in which more political turnover (less political stability) drives incumbents towards a transfer of resources from the future to the present.

Alesina and Drazen (1991) consider a bargaining game between coalition members and showed that the process of bargaining causes delays in enacting unpopular structural reform, thus weaker governments could be more inclined to run up debt. Roubini and Sachs (1989) bring empirical evidence for deficit bias being larger in countries with less stable political environments (more parties in the coalition, more frequent turnovers).

More recently, Bhandari et al. (2016) model a benevolent government that chooses optimal taxation and debt level allowing for risk premia due to correlation between debt security return and government spending. The paper finds that debt dynamics were related to the return-spending covariance.

Finally, institutional characteristics may play a role in both fiscal deficits and government debt. A case at hand is the recent drive towards setting up fiscal councils and legislating fiscal rules, which attempt to constrain government from following short-term political goals. Identification is difficult (fiscal rules may be enacted in countries that are more committed to balanced budgets anyway), but careful analyses generally support the case that fiscal rules are efficient tools to improve fiscal prudence (Heinemann, Osterloh and Kalb, 2014; Toth, 2016).

Does high debt hinder economic growth?

Before turning to the decision of repayment and default, it is worth to review the effect of government debt on economic output.

In the long-run, there is near general consensus that technological progress, the capital stock, the size and skills of the labor force are the factors that matter for economic growth. Based on this premise, governments may be able to affect long-run growth if they can promote labor force participation, human capital and technology and population growth. On the other hand, the main adverse long-term effect of budget deficits is that it reduces national savings and crowds out private investments, which leads to lower capital stocks and potential output (Gale and Orszag, 2002). The effects of fiscal deficits and growing debt is dependent on how efficiently and on what the government spends the extra resources.

Coming to empirical studies, Woo and Kumar (2015) estimate that high debt lowered future growth through the channel of lower accumulated capital stock. In this study, a 10 percent increase in the debt ratio is associated with a 0.2 percent decrease in real GDP growth. The effect is smaller for developed countries and the authors provide some evidence of non-linearity: higher debt ratios have more adverse growth effects. Eberhardt and Presbitero (2015) also report that higher debt levels are associated with lower growth and that the relationship is non-linear.

In contrast, Panizza and Presbitero (2014), using an instrumental variable technique show that the negative link between growth and debt ratio is largely tautological (GDP enters the denominator of the debt ratio, so any increase in the growth rate reduces the ratio). When controlling for this source of endogeneity the relationship becomes insignificant. On 40 years of Greek data Spilioti and Vamvoukas (2015) find a positive relationship between debt and growth.

Reinhart and Rogoff (2010) propose that the relationship between debt and growth is non-

linear: it is weak below a debt ratio of 90 percent, but is about 1 percentage point lower above that. [Égert \(2015\)](#) however rejects this assumption based on threshold autoregressions. [Égert \(2015\)](#) shows that the relationship between the debt ratio and growth is insignificant for emerging markets. For developed countries there is an estimated 20-40 percent threshold above which the relationship is negative.

In sum, evidence about the effect of debt levels on growth remains inconclusive.

2.2 Sovereign credit risk determination

Turning to sovereign credit risk determination, the next two subsections outline main characteristics of sovereign credit risk and then briefly present definitions and types of sovereign defaults. The main discussion follows thereafter, segmented into the two main motivations for experiencing sovereign defaults: the willingness to pay and ability to pay aspects. The discussion also entails a discussion of political economy aspects.

2.2.1 Distinguishing features of sovereign credit risk and its analysis

There are two key properties of sovereign credit risk with important implications for its analysis.

The first stems from the fact that sovereign governments cannot go bankrupt and sovereign debt contracts cannot be enforced in the way bankruptcy procedures enforce contracts in the private sector of a modern market economy. In particular, there are no superior authorities that could force governments in arrears of debt payments to reorganize their economic activity or to sell their assets and distribute the proceeds among debtholders: this is ruled out in case of domestically owed debt and has in practice also been unimportant in the case of external debt.

The fact that sovereigns can choose to honor debt payments or repudiate them puts credit analysis into a different perspective compared to the case of credit of private companies. Private companies default on debt when they are not able to obtain the necessary funds for repayments and are liquidated when they are found to be insolvent. Therefore in this case the key factors leading to default are illiquidity and insolvency, both aspects of the *ability to pay* oncoming obligations. In contrast, the fact that sovereigns can choose not to pay (in spite of being able to) is commonly referred to as the *willingness to pay* aspect, and has been the main focus of the sovereign credit risk literature since the seminal paper of [Eaton and Gersovitz \(1981\)](#), which developed the first formal model of this sovereign decision.¹²

[Krugman \(1985\)](#) argues that the ability to repay aspects in the case of sovereigns are less

¹² [Andritzky \(2006\)](#) recounts that the historical roots of sovereignty originate in the Peace of Augsburg in 1555 and the Peace of Westphalia in 1648 and are today included in the United Nations Charter which accepts the "political independence and territorial integrity" of sovereign states ([Andritzky, 2006](#), p.16). Immunity derived from sovereignty, and the further legal doctrines of the 'act of state' and 'international comity' have defended sovereign debtors from claims of external creditors. Although holdouts in some sovereign renegotiations have been successful in enforcing their claims, and enforceability strengthened during the past three decades, enforcement is still very difficult and has remained the exception ([Panizza, Sturzenegger and Zettelmeyer, 2009](#); [Schumacher, Trebesch and Enderlein, 2012](#); [Vidovics-Dancs, 2014](#)).

relevant, because if governments truly had only liquidity problems, they could still obtain funding from rational lenders. On the other hand their insolvency would contrast with rational lenders having lent them as much debt in the first place. [Krugman \(1985\)](#) mentions the possibility of lender irrationality and moral hazard (lenders might be counting on official lenders to bail sovereigns out), but dismisses these as unsatisfactory explanations.¹³ [Eaton, Gersovitz and Stiglitz \(1986\)](#) claim that net worth of sovereign borrowers is unimportant due to contracts not being enforceable, whereas illiquidity is often the consequence of investors pulling out money, which needs to be explained in the first place. [Panizza, Sturzenegger and Zettelmeyer \(2009\)](#) argue that even in the cases of default associated with inability to service debt, default could have been averted by drastic adjustments and so these events could in fact also fall under the heading of willingness to pay. Nonetheless in these cases the size of necessary adjustments makes default "excusable" in the terms of [Grossman and Huyck \(1985\)](#), which could imply smaller retaliation on part of creditors and therefore smaller costs of default.

Given that sovereigns can decide on defaulting, investors have to price government debt securities accordingly. This gives sovereign asset prices a strategic perspective with implications on the methodology of research in the sovereign risk area.

Another key difference between government debt and corporate (or household) debt that is crucial for credit risk analysis is that there are much fewer sovereigns than private companies and much fewer observed credit events in the case of government debt. Corporate credit risk analysis can compare fundamentals of defaulting and non-defaulting private companies and obtain more precise estimates on fundamental determinants even when the number of such factors affecting default is large. In sovereign credit risk analysis, it is hard to separate issuer characteristics from the prevailing circumstances (economic, financial conditions of the era), because default events do not happen simultaneously.

Moreover, default and restructuring have almost entirely been confined to developing countries, though the Greek restructuring in 2012 proves that advanced country bonds are not free of credit risk. If (as plausible) there are material differences as to how developing and advanced economies work, then results about default risk based on developing country experiences may not be extendable to advanced economies.

The infrequency of sovereign default observations has thus determined several facets of research. Authors who studied default events and crisis resolutions with statistical tools were motivated to reach far back in history ([Tomz and Wright, 2007](#); [Reinhart and Rogoff, 2011a](#); [Reinhart and Trebesch, 2016](#)). Other research instead analyzed fewer default observations, but in detailed case studies ([Andritzky, 2006](#); [Sturzenegger and Zettelmeyer, 2006](#); [Panizza, Sturzenegger and Zettelmeyer, 2009](#); [Zettelmeyer, Trebesch and Gulati, 2013](#)).

There have been empirical studies that directly regress incidence of default on fundamental characteristics (e.g. [Frank and Cline, 1971](#); [McFadden et al., 1985](#); [Georgievska et al., 2008](#), and further references therein), but compared to the vast literature that use sovereign credit

¹³These explanations are carefully elaborated, however, in the early work of [Guttentag and Herring \(1985\)](#).

risk proxies (ratings and spreads) as left-hand side variables, this strand constitutes a minority of the empirical literature. Most empirical studies used sovereign credit spreads or ratings as dependent variables since the 1990s, as secondary bond markets developed and gained liquidity. Credit ratings and sovereign credit spreads are both noisy and biased proxies of sovereign credit risk, but they have the benefit of providing continuous measures of such risk, contrary to default events.

2.2.2 Definitions and types of default

Some definitions are in place at this point regarding default. A very good description of concepts and one I follow here is by (Das, Papaioannou and Trebesch, 2012). Another very useful Hungarian reference is Vidovics-Dancs (2013).

Default in the stricter sense refers to missing debt service payments (interest or principal). A related concept is a payment moratorium, which is a decision to stop servicing all of debt. Default can also be partial or selective, when the payment moratorium only constitutes a subset of oncoming payments. Debt repudiation refers to announcement of (intended) non-payment and is usually reserved for the strategic (willingness to pay) aspect.

Debt restructuring may or may not involve defaults. There are several cases, when a government was in arrears with payments, but later it did not restructure debt and serviced it in full. (Asonuma and Trebesch, 2016, distinguish between these cases and explore differences in economic consequences). Milder forms of restructuring often involve maturity extensions and/or interest rate reductions (these reduce rollover risk: i.e. increases the ability to pay), or other changes to debt instruments (currency denomination, amortization, CAC, optional features, etc). Restructuring may also involve debt reduction, which results in lower outstanding notional debt amounts (Reinhart and Trebesch, 2016, explore different economic consequences of debt restructuring with and without debt reduction). From the point of view of investors, restructuring entails losses or haircuts, which may also be calculated in a variety of ways. Three popular methods are comparing (i) the present value of new bonds and the notional (face) value of old bonds (the market haircut in Sturzenegger and Zettelmeyer, 2006; Cruces and Trebesch, 2013), (ii) the present value of new and old bonds (proposed by Sturzenegger and Zettelmeyer, 2006; Cruces and Trebesch, 2013), (iii) the notional value of new and old bonds (the face value debt reduction). Restructuring may refer to the, often lengthy, debt renegotiation process, as well as its end result, which is the debt exchange.

Finally, a credit event is usually considered all of the above (i.e. default and default without restructuring). It is often used to refer specifically to the event at a single point in time that initiates the restructuring process. The ISDA definition (used for credit default swaps) entails either of missed payments (after a grace period), distressed debt restructuring (changing the terms of the debt instrument that lowers its value) and declared repudiation. Voluntary debt exchanges may not imply a credit event.

I use the term 'default' in a wider and imprecise sense (in line with common practice) that includes any form of credit events and also the restructuring process.

2.2.3 Costs and benefits of repaying debt: the willingness to pay problem

As mentioned above, the willingness and the ability of sovereigns to service their debt is not so clear-cut in practice. The two aspects have been intertwined in most default cases ([Panizza, Sturzenegger and Zettelmeyer, 2009](#)). Nonetheless this separation is still useful for analytic purposes and the review of the literature. I will proceed by reviewing the two aspects separately.

[Eaton and Gersovitz \(1981\)](#) provided the first formal theoretical model for the strategic default decision of the sovereign and considered several of its implications. The central assumption of the [Eaton and Gersovitz \(1981\)](#) paper is that the sovereigns choose to default if the benefits of defaulting exceed its costs. The benefit is the value of the debt outstanding (assuming full repudiation of debt servicing), thus higher debt levels increase the probability of default. The cost of default in this study is permanent exclusion from capital markets as the country completely loses its reputation of repaying debt.

The idea of strategic defaults implies that (rational) investors will only lend to governments if the costs of default are higher than benefits (or equivalently if the value, the net benefit, of default is lower compared to the value of repayment). In a world without uncertainty, debt levels may vary, but there will be no defaults. The model predicts lower debt levels in countries, where the benefit of defaults are higher and/or the costs of default are lower.

On the other hand, in a world with uncertainty, investors will lend according to calculations about the expected value of the benefit minus cost of default, which is the basis of the strategic default decision. The expected value of the net benefit of a default may be lower than its concrete realization, therefore defaults will occur. In the [Eaton and Gersovitz \(1981\)](#) model, default is more likely when a low state of income is realized, because debt servicing in these states have a higher utility cost and hence the relative value of default is higher. Default probability will increase more when there is larger uncertainty regarding the income process and when the curvature of the utility function is larger.

Formally, the belief about the future strategic policy choice of the government about default or repayment $P^g = \{D, R\}$ depends on the perceived probability of the relative value of repayment compared to default:

$$Pr[P^g = D] = Pr[V^D > V^R], \quad (2.3)$$

where V^D and V^R denote the values of a strategic default and repayment, respectively. The probability expresses the uncertainty about the value functions due to uncertainty about future shocks affecting these functions. When the shocks are realized, there is no uncertainty and the default decision is deterministic. Notably, uncertainty in the [Eaton and Gersovitz \(1981\)](#) model (and in most of the sovereign literature) refers to realization of output states, but the concept

can be extended to uncertainty about any benefits or costs of default. [Edwards \(1983\)](#) starts out from a theoretical model in which the cost of default is uncertain. [Krugman \(1985\)](#) considers two types of uncertainty: trade sanctions and future growth shocks.

Note that the (commonly made) assumptions that investors know the reaction function of the sovereign and that they have the same information as the sovereign, leads to the same perception of default probability in the case of investors and sovereigns.

The above equation for strategic default choice can be applied independently of what the nature of default costs and benefits are. This is important because assumptions about benefits and costs of default have been subject to a lengthy and unresolved debate, that has also evolved through time ([Vidovics-Dancs, 2014](#)). This is the subject matter we turn to next.

Benefit of strategic default: debt relief

In much of the literature the benefit of default is simply the size of debt relief (face value reduction or the notional/market value of the haircut). The mainstream of the theoretical (following the classical line of [Eaton and Gersovitz, 1981](#); [Edwards, 1983](#)) and more recent quantitative literature ([Aguar and Gopinath, 2006](#); [Arellano, 2008](#)) assumes full debt repudiation. The implicit rationale is that public debt is valued as the sum of its discounted future debt service cash flows and that debt service is 'lost' to current domestic consumption, the objective function.¹⁴ Although the classic literature and many more recent studies use the abstraction of full debt repudiation, this is a theoretical possibility because none of past incidences of debt relief included a full debt writedown. The choice of particularities of the resolution/restructuring process is the subject of a large theoretical and empirical literature strand (see [Andritzky, 2006](#); [Das, Pappaioannou and Trebesch, 2012](#), for thorough discussions).

Empirical studies report wide variability of recovery rates. On an emerging market sample between 1978-2010 [Reinhart and Trebesch \(2016\)](#) show that debt relief in debt restructuring episodes varied considerably (were between 2-55% of GDP) with an average of 16% of GDP and 36% of the debt outstanding. [Sturzenegger and Zettelmeyer \(2007\)](#) estimated bond-by-bond haircuts (investor losses) in six default events to be in the 13-73% range, although most were in the 25-35% range (haircut to face value was usually somewhat larger). In the estimate of [Benjamin and Wright \(2009\)](#) investor losses in default were on average 45% pre-1995 (similar to Brady bond restructurings as reported by [Andritzky, 2006](#), Table 2.1) and 22% after 1995. [Cruces and Trebesch \(2013\)](#) also show that the tendency of increasing haircuts in time is connected to a larger incidence of debt restructuring involving face value reductions of debt.¹⁵

To explain why partial repudiations occur, it is logical to assume that the cost of default

¹⁴[Reinhart and Trebesch \(2016\)](#) evaluate explicitly the benefits of debt relief such as improvement in ratings and later economic output. They find that in case the debt restructuring involves face value reductions (not just maturity extensions or interest rate reduction), then economic output increases and ratings improve.

¹⁵Industry estimates for the recovery rate, the notional minus the losses, are usually more conservative: on Bloomberg, for example, recovery rate for emerging market sovereign bonds are assumed to be only 20%, whereas they are 45% for developed countries

also depends non-linearly on this choice: namely, if a higher haircut increases costs disproportionately, then the government is better off choosing a lower haircut. One possibility is that lenders may retaliate more if the borrower is judged to be able to repay debt easily. If, on the other hand, the default decision comes after an unexpected adverse shock, default may be considered as more "excusable" (Grossman and Huyck, 1985). Default may then entail quicker negotiations, shorter exclusion from markets, reduced sanctions and lower output losses.

Asonuma and Trebesch (2016) distinguish between preemptive restructurings (where start of renegotiations precedes default) and post-default restructurings. They show on a database of 111 episodes that preemptive restructurings involved smaller haircuts and have better outcomes: are usually quicker to negotiate and resulted in smaller output losses. Outright defaults and renegotiations after these, on the other hand, were more often associated with unexpected adverse shocks. Asonuma and Trebesch (2016) also show that preemptive restructurings usually take place when the default risk is already high (the sovereign is in a bad economic state), whereas the post-default cases could be rather associated with unexpected adverse shocks.

Several papers emphasize the game theoretic aspects of the continued relation between borrowers and lenders (i.e. their relational contract) in repeated games models. These models are particularly useful for analysing debt negotiations between creditors and the debtor sovereign and the coordination between creditors. In this vein, Bulow and Rogoff (1989a), Kletzer and Wright (2000), Kovrijnykh and Szentes (2007), Benczúr and Ilut (2016) all view (potential) debt rescheduling as an integral part of a continuously renegotiable contract between creditors and debtors (i.e. repeated games). If such contracts can be assumed to be long-standing (i.e. creditors are largely the same group), then creditors may impose penalties on defaulting sovereigns as well as on creditors that do not participate in the punishment of the sovereign (see next heading).

In the model of Yue (2010), the endogenous repayment rate depends on the relative bargaining power of lenders and the borrower: borrowers in this model set the recovery rate in view of the duration of exclusion from markets. Bai and Zhang (2012) consider the duration of renegotiations in a model of dynamic bargaining. Waiting is costly for government, but it has the benefit to find out where creditor reservation values are. Benjamin and Wright (2009) rather attributes the delays in renegotiations to creditors being motivated to wait until future default risk by the creditor on the settlement agreement is lowered. Restructuring too soon would motivate debtors to default on settlement agreement and creditors would be worse off, even though on aggregate (considering both creditors and lenders) an early resolution would be optimal. This provides an explanation as to why defaults tend to occur not at the trough, but in already recovery phases of recessions as observed by Yeyati and Panizza (2011). In the models of Kovrijnykh and Szentes (2007) and Bi (2008), too, investors and borrowers wait until good growth shocks to restructure as a monopolist lender allows reaccess to markets, when growth improves, but keeps the sovereign out of the market to extract monopolist rent when the default occurs in bad times. In Bi (2008) this occurs, because both sides wait for a 'larger cake' to be distributed. Sunder-Plassmann (2018) model how creditor and debtor bargaining power vary over the business cycle

and explain why recovery rates in debt renegotiations tend to positively correlate with economic output.

Resolution often entails a bailout by official creditors, such as the International Monetary Fund, which increases the recovery rates private investors can expect and serves as an insurance for governments in case external shocks hinder their repayment abilities. The possibility of bailout, however, leads to moral hazard on the part of both lenders and governments. A consequence is higher debt levels (see e.g. [Andritzky, 2006](#); [Corsetti et al., 2013](#)). Government moral hazard is reduced by demanding conditionality in exchange for bailouts. [Fink and Scholl \(2016\)](#) model the optimal level of conditionality. Stricter conditionality imposed leads to lower debt levels in their model and hence reduces risk, but it has a two-pronged effect as it also leads to lower willingness to participate, which increases risk. [Bjørnskov and Schröder \(2013\)](#) claim that foreign aid reduces repayment incentives. They model renegotiation as a war of attrition between government and lenders and foreign aid tips the outcome in favor of government, because it allows government to wait longer until they get better terms.

Traditional costs of default: reputation (market exclusion) and sanctions

Assessing the costs of default have been less straightforward. [Panizza, Sturzenegger and Zettelmeyer \(2009\)](#) group the types of costs into costs related to reputation (exclusion from debt markets); direct sanctions (seizing international assets or trade credit); domestic economic costs of default (fear of a recession or a financial crisis); and political costs (loss of political power). [Panizza, Sturzenegger and Zettelmeyer \(2009\)](#) tend to favor political costs, because they find less compelling evidence of high costs in the other three categories.

[Panizza, Sturzenegger and Zettelmeyer \(2009\)](#) recount two main problems with the initial reputation cost theories. First, in the [Eaton and Gersovitz \(1981\)](#) model debt serves the purpose to smooth consumption and insure against bad times. However, as put forward by [Bulow and Rogoff \(1989b\)](#), the borrower may then simply borrow and invest the funds without repaying and receiving interest, and using the funds to insure against output from fluctuations. This would prohibit lending in the first place. Most models continuing on the reputation tradition therefore assume borrowers cannot have international assets.

Second, several studies ([Eaton, Gersovitz and Stiglitz, 1986](#); [Bulow and Rogoff, 1989a](#), and others) note that the exclusion of the borrower from markets is dynamically inconsistent, because after debt relief occurs lending to a defaulted government could be profitable again. This results in a coordination problem between lenders: current lenders are more interested in punishing the borrower for repudiation than potential new lenders. Another coordination aspect is that current lenders may have a collective interest in bridge lending, in the hope that a positive shock allows the sovereign borrower to choose repaying debt, even though individually each lender would withdraw from further lending ([Krugman, 1985](#)). A related coordination problem emphasized by [Sachs \(1983\)](#) is that if there is a widespread belief that other investors will not lend, this will be self-fulfilling and will lead to another equilibrium, in which no investors lend and the

borrower defaults. This aspect will be discussed later in more detail.

A third argument for reputation costs not being sufficient explanations is empirical: [Panizza, Sturzenegger and Zettelmeyer \(2009\)](#) report that market exclusions had the duration of roughly 5 years for loan contracts, and 1 year for bond defaults, which means hardly any deterrent regarding business cycle smoothing. Individual cases vary, but there is no evidence of permanent exclusions from debt markets.

As alluded to before a theoretical strand characterizes the investor-borrower relationship as a repeated game, where both parties may dynamically renegotiate contracts. [Bulow and Rogoff \(1989a\)](#) argues that due to the creditor coordination problem regarding the market exclusion of a defaulting government, it is only direct sanctions (seizing international assets of defaulters or restricting trade credit) that may credibly deter governments from defaulting. Noting that international assets are usually small relative to outstanding debt, they favor the argument based on trade restrictions. By this argument larger dependence on foreign trade (imports) is what reduces default risk and hence enables higher debt levels. [Krugman \(1985\)](#) also models costs of default as owing to trade sanctions arguing that trade credit is the discretion of developed country banks. The problem with the direct sanctions argument is that empirical data tell us that such costs were again not so large as to deter defaults ([English, 1996](#); [Panizza, Sturzenegger and Zettelmeyer, 2009](#)).

[Kletzer and Wright \(2000\)](#) on the other hand attempt to save the classic penalties argument on the basis of an automatic mechanism for creditor coordination, which assumes that creditors do retaliate on defaulters (punishing them by temporary exclusion and worse renegotiated lending), and ward off new lenders with the threat that if they were to lend the borrower that chooses default, the previous creditors could also forgive the borrowers defaulting on the new loans. Then, new lending would not be profitable, which keeps the current threat of retaliation on default credible.

[Cruces and Trebesch \(2013\)](#) show that higher haircuts were associated with longer market exclusion duration as well as higher credit spreads. [Benczúr and Ilut \(2016\)](#) also lends empirical support to the penalties arguments in showing that the history of defaults significantly increase later funding costs. These authors further show that this increase is not just due to changed perceptions of default probability. [Phan \(2017\)](#) claims that currency depreciations serve as the key channel of punishment.

Other economic costs of default: growth slowdown and crisis

Many studies consider economic costs other than the traditional costs of trade exclusion and sanctions. Most of these relate to adverse impacts of default on domestic economic output and/or raising the spectre of a domestic financial crisis. Economic slowdown may be a result of reduced investments and/or consumption either due to unavailability of credit (due to for instance problems with financial intermediaries) or reduced demand for credit (due to a general drive to deleverage).

Cole and Kehoe (1998) proposes a more general reputation argument than Eaton and Gersovitz (1981). A sovereign default in their model signals that government is not trustworthy, which has spillover effects on other parts of the economy and this entails output costs additional to those due to lost government market access. Similar to Cole and Kehoe (1998), Sandleris (2008) claims that sovereign defaults has a signalling effect although of a different kind: it informs of weak fundamentals and the resulting implication may be lower foreign and domestic investments and a credit crunch for private agents.

A domestic cost of the default decision (or a deteriorating government fiscal position that increases this risk) may be lost international market access for domestic firms. Das, Papaioannou and Trebesch (2012) report empirical evidence on a sample of 31 emerging markets that is supportive for such a theory. In Brutti (2011) government considers default costly, because government securities are a source of liquidity for domestic agents, so a default triggers a liquidity crisis. Mendoza and Yue (2012) instead proposes a channel through international trade: the market exclusion following a default restricts imports and its imperfect domestic substitution results in a productivity shock.

The complicated interactions between sovereign credit risk and the credit risk of financial intermediaries received increased attention in economics and finance since the 2007-2009 financial crisis and the eurozone sovereign crisis. This recent strand of the literature emphasizes a two-way link between the health of the banking system and sovereign credit risk. Governments are affected by the health of the banking system owing to the contingent liability they represent: in case of a banking system crisis a government bailout of banks can abruptly boost sovereign debt levels, which increases the benefit of a sovereign default. The bailout improves banking sector balance sheets, so bailouts are a source of private-to-public credit risk transfer. On the other hand, banks hold government bonds, thereby an increase in sovereign risk reduces the value of their government securities worsening solvency and liquidity positions.

Acharya, Drechsler and Schnabl (2014) model many of these aspects. In this paper, governments bring decision about bailouts (transfer to banks) and default to maximize household utility. The optimum bailout increases with bank debt and decreases with government debt. Government default is more attractive when both bank debt and government debt are high, but is less attractive when the fraction of government debt held by banks is larger. The model implies that CDS spreads depend on government and bank debt only above a threshold, which is when government begins to dilute debt (issues debt in excess of what it can later recover in taxes). Acharya, Drechsler and Schnabl (2014) show that empirically sovereign bailouts of banks led to increased sovereign spreads and later on bank CDS spreads co-moved with sovereign CDS (even controlling for fundamentals).

In Gennaioli, Martin and Rossi (2014), as well, governments consider the effect of their default on the domestic bank sector. More developed financial markets result in higher costs of default due to larger exposure of banks to government securities, which are used as liquid assets. A default in these cases, especially if complemented by external bank debt, is likely

to reduce private credit and growth. The model of [Bolton and Jeanne \(2011\)](#) is different in that it emphasizes the collateral value of government bonds for banks, but is similar in that the sovereign default undermines bank balance sheets. The cost this entails has the consequence that default is less likely when banks hold much of these assets.

More concretely, the rationale for why the sovereign–bank nexus affects government willingness to pay in these models is that default restricts private credit and constrains consumption growth for households ([Acharya, Drechsler and Schnabl, 2014](#); [Gennaioli, Martin and Rossi, 2014](#)). In [Bocola \(2016\)](#) lending is reduced due to banks deleveraging or banks being funding-constrained, which slows growth.

Several empirical papers dealt with the sovereign–bank nexus. Sovereign credit was shown to be affected by bank bailouts ([Mody, 2009](#); [Dieckmann and Plank, 2011](#)) or the increased probability of bailouts as proxied by the riskiness of their banking sector ([Zoli and Sgherri, 2009](#); [Ejsing and Lemke, 2011](#); [Alter and Schüler, 2012](#); [Kallestrup, Lando and Murgoci, 2016](#)). On the other hand, for instance [Buschmann and Schmaltz \(2016\)](#) and [Bocola \(2016\)](#) brought evidence of bank credit risk being affected by sovereign credit risk. The two-way interdependence between bank and sovereign credit risk was empirically supported by many authors ([De Bruyckere et al., 2013](#); [Banerjee, Hung and Lo, 2016](#); [Betz et al., 2016](#); [Pagano and Sedunov, 2016](#); [Gibson, Hall and Tavlás, 2017](#)).

Another channel through which sovereign debt problems may lead to output declines are capital flight and sudden stops. When foreign investors perceive an increase in sovereign credit risk this reduces their demand for domestic assets, in particular government securities. In floating regimes exchange rate depreciation ensues, which results in balance sheet deterioration for entities with foreign currency liabilities ([Gereben, Karvalits and Kocsis, 2011](#); [Benczur and Konya, 2016](#)).

Studying the causality linking sovereign defaults and economic growth is not straightforward. Based on the above arguments about the adverse impact of default (or its risk) on the banking sector and availability of credit for the private sector, there is a strong case that defaults may cause output to decline. However, theory also predicts that defaults will be caused by a slowing output, because government debt serves as an insurance policy for exactly these situations. This correlation is reinforced empirically as defaults tended to happen during downturns, although [Tomz and Wright \(2007\)](#) notes that the association is weaker than predicted by calibrated theoretical models such as [Aguiar and Gopinath \(2006\)](#).

[Yeyati and Panizza \(2011\)](#) find that default does not predict lower growth, in fact growth usually recovers after default. The authors suggest that the reason might be that anticipation of sovereign default already leads to lower growth, so that the (output) costs of sovereign problems materialize before the default. If this is the case, however, sovereigns should have already repudiated payments before. [Yeyati and Panizza \(2011\)](#) posit that the delay in the default decision could be a result of either anticipating lower costs of default this way (by the argument that default is more "excusable" if costs have materialized) or a consequence of politicians anticipating

large personal political costs for entering a default (Borensztein and Panizza, 2009).

Showing that banking crises resulted in lower economic growth is more straightforward. Influential empirical papers (Laeven and Valencia, 2008; Reinhart and Rogoff, 2009) demonstrated this link throughout history. Reinhart and Rogoff (2009) found that on average economic output fell by 9 percent in banking crises. Laeven and Valencia (2012) estimated median output losses of 23 percent, but this masks a wide variability in the distribution. Romer and Romer (2017a) find an average 6 percent decline in real GDP. In view of the link between sovereign default and bank balance sheets, such output costs could be a deterrent for default decisions. Also, both the studies of Reinhart and Rogoff (2009) and Laeven and Valencia (2012) found that banking crises usually resulted in large increases in public debt levels. Reinhart and Rogoff (2009) argue that this is a result of fiscal deficits due to the economic slowdown. A recent paper by Muir (2017) finds on a historical database that interest rate premia usually increased in financial crises, but not in simple recessions, even though consumption and consumption volatility were similar in the two.

Still, incidence of twin crises was rare. Laeven and Valencia (2012) reports that only 1 percent of sovereign defaults preceded a banking crisis and 5 percent of banking crises were followed by sovereign default. While this could weaken the argument that governments should worry about sovereign default causing output to collapse due to an ensuing banking crisis, it may also be the case that such twin events are not observed frequently exactly because of such fears. Governments may choose to repay over defaulting in cases where a default is expected to trigger a banking crisis.

Fundamental effects on the willingness to repay

Table 2.1 outlines some of the key links between country fundamentals and the willingness to pay aspect of sovereign credit risk. To recap, much of this strand of the literature views sovereign defaults as a result of a cost-benefit analysis. The main benefit of default is the extra consumption that is won by not repaying debt, hence higher debt ratios increase the motivation and probability of default. Moreover, marginal utility of extra consumption is highest in downturns, which leads to the prediction of more defaults in downturns. Slow economic growth may persuade lenders to forgive governments defaulting, which lowers the costs (and hence raises the probability) of defaults in downturns. Higher output volatility makes debt more valuable on the one hand, hence lowers the incentive to default. On the other hand it causes higher incidence of downturn states, where default is more likely. A stochastic versus stable growth trend also predicts higher default occurrence (Aguiar and Gopinath, 2006).

Mainstream models in this strand are ambivalent about the correlation of current account and sovereign risk. (These models only consider public external indebtedness and hence trade balance, current account and fiscal balances equal and are endogenously determined by other variables in the model.) Current accounts are motivated to improve in booms due to consumption smoothing, which would yield positive correlation between current account balances and default

probability, something contested by empirical data. On the other hand, however, current account improvement decreases external indebtedness, which would result in a negative correlation.

Table 2.1: Theoretical effects of fundamentals on sovereign risk (willingness to pay aspect)

Fundamental	SIGN	Rationale	References
debt ratio, debt service payments	+	increases the benefit of debt repudiation	EG, AG, Are, Edw
real economic growth	-	default (debt relief) has less value when growth is high, decreasing prob.of default	AG, Are
recent past economic growth	-	if high, creditors less likely to forgive the government for defaulting (raises cost of defaulting, so decreases PD)	GH
output volatility	?	value of debt to smooth business cycle higher less inclined to default; but higher incidence of downturns	EG, AG
current account balance	?	higher balance contributes to lower external indebtedness	EG, AG, Are, Edw
level of foreign assets, reserves	-	if high: more to be sanctioned, creditors less forgiving, raises costs of PD, lowers PD	BR, Edw
trade openness	-	if high: trade sanction costs of default larger, less likely to default	BR, Kru, MY
financial integration with the world economy	-	if high: domestic sector hit by restricted access to international capital markets	CK
domestic share of government debt (x fin.development)	-	if high: risks output loss through credit crunch, balance sheet mismatches, banking crisis	Bru, ADS, GMR, BJ
foreign currency liabilities	-	if high: exchange rate depreciation due to default entails costly for the economy	Phan
share of public debt held by residents favored by government	-	if high: costs of default are higher	SSZ, EM
perceived domestic political costs	-	higher political costs of default, lowers probability of default	PSZ, BP
perceived international political costs	-	if high: more political capital to lose	BGM
availability of international bailouts	+	increases overborrowing and moral hazard	AG

Sources: author's compilation.

Notes: References in the table are abbreviated as follows.

EG: [Eaton and Gersovitz \(1981\)](#), AG: [Aguar and Gopinath \(2006\)](#), Are: [Arellano \(2008\)](#), Edw: [Edwards \(1983\)](#), GH: [Grossman and Huyck \(1985\)](#), BR: [Bulow and Rogoff \(1989a\)](#), Kru: [Krugman \(1985\)](#), MY: [Mendoza and Yue \(2012\)](#), CK: [Cole and Kehoe \(1998\)](#), Bru: [Brutti \(2011\)](#), ADS: [Acharya, Drechsler and Schnabl \(2014\)](#), GMR: [Gennaioli, Martin and Rossi \(2014\)](#), BJ: [Bolton and Jeanne \(2011\)](#), Phan: [Phan \(2017\)](#), SSZ: [Song, Storesletten and Zilibotti \(2012\)](#), EM: [D'Erasmus and Mendoza \(2016\)](#), PSZ: [Panizza, Sturzenegger and Zettelmeyer \(2009\)](#), BP: [Borensztein and Panizza \(2009\)](#), BGM: [Baldacci, Gupta and Mati \(2008\)](#).

The sanctions argument implies that higher trade openness, larger international assets of a country expose them more to retaliation and thus increases default. This would in turn lower default risk. Similarly, in the general reputation model of [Cole and Kehoe \(1998\)](#) perceived costs to the private domestic economy may increase in default and this effect may be considered to be larger the more integrated a country is with the world economy. As outlined in the last subsection defaults may also lead to economic costs via hurting the financial system by lowering the collateral value or liquidity, these costs are perceived to increase with domestically held debt and with an increasing role of financial intermediation in the economy.

The last rows of the table refer to increasing political risks due to default, which also act to decrease the willingness to repudiate debt. These are elaborated later in the section.

2.2.4 The ability to pay problem

Much of early theoretical modelling was concerned with strategic defaults. The underlying argument (e.g. [Krugman, 1985](#)) is that rational lenders would not lend to insolvent borrowers, that governments usually have assets far exceeding debt levels and that illiquidity is itself a consequence of anticipated strategic defaults to be explained.

However, solvency or debt sustainability aspects become important when there are critical levels of debt servicing that may be regarded as levels feasible politically, i.e. without social unrest. They may become important in a debt trap scenario: the case when the debt ratio reaches a critical level where the process for the debt ratio turns explosive, in which case default is unavoidable ([Ghosh et al., 2013](#); [Ghosh, Ostry and Qureshi, 2013](#); [Bølstad and Elhardt, 2017](#)).

Ability to pay due to liquidity issues, is also an important factor of sovereign defaults. Early papers in the 1980s already pointed out the possibility of multiple equilibria, a consequence of investor expectations about other investors beliefs. As explained below, small changes in fundamentals, beliefs or external shocks may then lead to withdrawal of funding, which (without external help) forces government into default even if the costs of default are perceived higher than its benefits and if otherwise the debt ratio would appear sustainable.

It could be argued that lenders would calculate with these possibilities and would not lend so much in the first place to reach debt levels, which are unsustainable or threaten self-fulfilling liquidity crises. However, several factors support the case for overlending/overborrowing. Already the early study of [Guttentag and Herring \(1985\)](#) supplies three different (compelling) arguments: (1) rationality of investors may be bounded due to the behavioral biases of availability (i.e. default was observed long time ago and is therefore considered a low probability event), threshold heuristic (low probability events are completely ignored) and cognitive dissonance (defending previous decisions even in light of contrasting evidence); (2) investors may have inadequate information; (3) moral hazard: investors may calculate with an official sector bailout.

The influential paper of [Reinhart and Rogoff \(2008\)](#), 'This Time is Different: Eight Centuries of Financial Folly', shows that sovereign defaults are clustered in time and suggests that these clusters are a consequence of the tendency of emerging market countries to overborrow in good times, itself supported by both bounded rationality on part of investors and interest rate cycles of financial centers. Recently, [Bordalo, Gennaioli and Shleifer \(2016\)](#) refer to the representativeness and base rate behavioral biases to argue that investors tend to overweigh the current state of fundamentals and make extrapolations based on these. They show that these result in credit cycles, because overoptimism results in overinvestment in good times, which also results in predictable reversals. [Eaton, Gersovitz and Stiglitz \(1986\)](#) contemplate information asymmetries and the resulting adverse selection of lenders (overlending to risky borrowers) and moral hazard explanations have also been discussed in this paper and others from early on in the literature (see [Andritzky, 2006](#), for references).

Solvency aspects (debt sustainability)

That said, debt sustainability analysis is not immune from the critique that governments usually have at their disposal much larger assets (state-owned assets, future and current taxable incomes) than financial liabilities, so that a sufficiently large effort could bring finances back into sustainable territory. If the government is expected to repudiate debt well before such levels are reached because such adjustments are unfeasible politically, then sustainability is a willingness to pay aspect after all.

Debt sustainability analysis takes an empirical approach and examines whether dynamics of variables that delineate future debt ratio trajectories have a stationary or an explosive path.¹⁶ If debt dynamics are on an explosive path then the government is in a debt trap and a default (although still an unwillingness to repay) only stops the process reaching levels where the sovereign becomes truly unable to pay (assuming state assets cannot be sold and further wealth taxes cannot be collected, then a theoretical limit is reached when debt becomes so large that interest payments reach GDP). Timing could be important, of course, if there are exogenous positive shocks that can occur and that can break the debt trap.

Debt sustainability analysis gauges whether fiscal policy (the reaction function of the primary balance to the debt ratio) is such that it stabilizes the debt trajectory. Following standard derivations in the literature, divide equation (2.1) by the level of real GDP at the end of the last period, Y_{t-1} , and use $Y_{t-1} = Y_t/(1 + g_t)$, to get the following expression for the debt ratio dynamics:

$$\frac{D_t(1 + g_t)}{Y_t} - \frac{D_{t-1}}{Y_{t-1}} = -\frac{PB_t(1 + g_t)}{Y_t} + r_t \frac{D_{t-1}}{Y_{t-1}}. \quad (2.4)$$

Then, denoting the public debt-to-GDP and fiscal balance to GDP ratios by d_t and pb_t , respectively:

$$\begin{aligned} d_t - d_{t-1} &= -pb_t(1 + g_t) + r_t d_{t-1} - g_t d_t = -pb_t + d_{t-1}(r_t - g_t \frac{1 + r_t}{1 + g_t}), \\ \Delta d_t &= -pb_t + d_{t-1} \frac{r_t - g_t}{1 + g_t}, \end{aligned} \quad (2.5)$$

Since $1 + g_t > 0$ a positive initial debt ratio will converge to zero in the limit, when

$$pb_t \geq d_{t-1}(r_t - g_t). \quad (2.6)$$

Based on this equation,¹⁷ one can analyze whether pb_t does sufficiently adjust to counter any increases in the debt ratio and the difference between real rates and growth. The setup

¹⁶These studies sidestep the issue of why dynamics are the way they are, accept dynamics as observed and assume that dynamics can be extrapolated into the future.

¹⁷The primary balance can be even lower for the debt ratio to be converging to zero given larger real growth rates. Most studies, however, abstract from the $1 + g_t$ denominator in equation (2.5) and therefore equation (2.6) is the inequality that distinguishes sustainable and unsustainable primary balances.

is particularly useful because the primary balance is at the discretion of the sovereign at each moment in time, whereas other variables are not directly in its scope.¹⁸

If there are estimates for r_t , g_t , the initial debt level could be used to calculate the average primary surplus needed for a stable ratio. This could then be contrasted with projections of the primary balance to gauge whether additional adjustments are needed.

A popular approach is to estimate the reaction function of the government on historical data using an econometric model. Then estimated parameters can be used to judge whether the fiscal policy sufficiently adjusted when faced with increases in the debt level. For instance, on U.S. data [Bohn \(1998\)](#) estimates an econometric specification $pb_t = \mu + \rho d_t + \beta Z_t + \epsilon$, where Z_t are cyclical adjustment controls. The paper shows that if the coefficient ρ is significant positive and factors in Z are bounded, then this is sufficient to guarantee non-explosive debt dynamics. [Bohn \(1998\)](#) finds that U.S. fiscal policy did adjust in a way that stabilizes the debt ratio.

[Mendoza and Ostry \(2008\)](#) investigates a similar specification for a panel of emerging market and developed countries. The authors reported estimates that supported debt sustainability in most countries with lower debt levels, but did not find significant adjustment in the group of countries with high debt ratios. These results may therefore present an additional factor, besides willingness to pay arguments, why investors should be wary of higher debt ratios when judging default probabilities.

[Ghosh et al. \(2013\)](#) use these insights to propose a more theoretical model of debt sustainability. The key assumption of the model is that governments have a fiscal reaction function, which increases in the debt ratio, but at a slowing pace (the authors call this tendency fiscal fatigue). As the debt ratio rises, governments increase the primary balance upward. However the marginal increase becomes smaller and eventually levels off. Then (assuming $r > g$), there exists a level of the debt ratio, where the fiscal adjustment is not sufficient to keep the debt ratio stable (the condition of equation 2.6 is not met). This is the sustainable debt limit, above which debt dynamics becomes explosive.

This model explains how investor beliefs about fiscal sustainability can swiftly reverse due to shocks to the debt ratio, interest rate and/or growth, especially if we take into account the endogeneity of interest rates to sustainability deliberations. Investor and analyst comments in the financial media during the Greek debt crisis strongly support that such sustainability deliberations were important. The impact of incoming data on such beliefs (and heterogeneity of opinions about Greek sustainability) may provide an explanation about the volatility of credit risk spreads seen at the time. A shortcoming of the analysis, though, is that it relies on homogeneity of the fiscal fatigue function (there are country fixed effects and control variables but these influence the constant of the regression not the sensitivity of the primary balance to the

¹⁸This is a simplified case. In reality, fiscal rules may tie the hand of government and the government may have the scope to influence the debt ratio by debt repudiation. When the central bank is not independent, the government may directly influence (nominal) interest rates as well, which may affect real rates, at least temporarily. Even when the central bank is independent fiscal policy may affect monetary policy indirectly through affecting variables that determine monetary policy rules.

debt ratio). Also variables of the model (debt ratio, interest rates, growth) are themselves dynamically dependent on one another and taking this into account would probably alter (plausibly lower) empirical estimates of the sustainable debt limit.

In an empirical paper, [Afonso and Jalles \(2017\)](#) allow the coefficient on the debt ratio to vary in time and find that the primary balance reacted more to changes in the debt ratio (sustainability increases) in cases when the budget balance was larger, when the country had better quality institutions, when a larger share of the debt was long-term or foreign currency denominated, and when more of the debt was held by the central bank.

Country regressions¹⁹ reveal however that most of these findings are in fact not due to time-variation, but rather to cross-country differences. Only two factors seem to be robust in influencing changes in the sustainability parameter: the budget balance and central bank holdings of debt. The real growth rate was insignificant in these regressions.

[Toth \(2011\)](#) evaluates debt sustainability methods ex post, by analyzing predictions of five different methods based on European data and checking whether these accurately differentiated between cases that were later found to be unsustainable and sustainable (measured by the country turning to international assistance or not). The paper finds most measures to have low statistical accuracy.

Other empirical papers endeavor to take the possible endogenous relationship between variables into account. [Abel and Kobor \(2011\)](#) estimate a VAR model for the Hungarian economy to recover debt path projections. A similar exercise is done by [Garcia and Rigobon \(2004\)](#) for Brazil. This paper also examines how uncertainty about the debt ratio evolved in the projection. [Genberg and Sulstarova \(2008\)](#) instead use (ad hoc) coefficient restrictions between variables to simulate future debt ratios. [Genberg and Sulstarova \(2008\)](#) however estimate the determination of interest rate spreads econometrically and find that the upper tail risk of the future debt ratio significantly affects interest rates. This finding is important regarding both solvency and liquidity considerations.

[Uribe and Yue \(2006\)](#) study the endogeneity of world and country interest rates with respect to real growth in a VAR model. This analysis reports that increases in U.S. rates first lower, then raise emerging market spreads and that about 20 percent of output fluctuations are explained by world rates and 12 percent by country spreads. Output shocks are also shown to have a significant effect on country spreads. A recent paper by [López-Salido, Stein and Zakrajšek \(2017\)](#) finds that interest rate spreads predict output two years later and bring evidence of this relationship being causal. [Baksa and Konya \(2017\)](#) also find that interest premium shocks are important in growth fluctuations for Central Eastern European countries, especially in the case of heavily indebted Hungary.

[Mellar \(2003\)](#) analyzes debt dynamics subject to various assumptions on the endogenous relationship between real growth, real interest rates and the primary balance. [Mellar \(2003\)](#) shows various constellations under which debt dynamics becomes explosive. One can read out

¹⁹[Afonso and Jalles \(2017\)](#), p.151, Table 4)

from this analysis that debt sustainability partly depends on assumed relationships between key macroeconomic variables.

This point relates to the subject matter of the thesis: were such endogenous relationships (or beliefs thereof) between macroeconomic variables to change in an adverse way, this could be enough to change the perception that a given debt level is unsustainable.

Such changes in relationships between variables are similar to the concept of 'wake-up calls' or 'fundamental-based contagion' considered by several papers in the sovereign risk literature (e.g Moser, 2003; Dasgupta, Leon-Gonzalez and Shortland, 2011; Beirne and Fratzscher, 2013; Bekaert, Harvey, Lundblad and Siegel, 2014). 'Fundamental-based contagion' or 'wake-up calls' arise, when investors update their beliefs about the effect of a fundamental factor on financial market indicators (sovereign credit spreads, equity indices, exchange rates). However, the aforementioned changes are more general, because beliefs can change about any parameter in the endogenous relationship of fundamentals not only the parameters representing effects of fundamentals on sovereign spreads.

Another perspective on how debt sustainability can become a key influence on default risk relates to banking and currency crises. If the threat of a systemic banking crisis rises, then due to (bank bailout) contingent liabilities there is an increasing chance that government debt levels may sharply increase raising it into a region, where repaying the full amount of debt is not possible anymore. In a similar vein, if the country has a significant amount of foreign exchange denominated debt, then a currency crisis or its risk may also threaten an abrupt increase in the debt ratio.

Table 2.2 summarizes fundamental effects on sovereign risk from the solvency aspect of the ability to repay motivation. The key issue regarding solvency, is how the actual debt level relates to a sustainable debt limit above which the sovereign is not considered solvent anymore and it considered unable to honor its commitments. Higher debt levels and factors contributing to debt increase therefore increase sovereign risk in this aspect.

Studies in this strand start out from the textbook (tautological) relationship between constituents of debt change (debt increases due to real interest payments on debt, and decreases due to primary surplus and real growth) and most are occupied with investigating the endogenized primary balance variable (whether it reacts to the debt ratio and whether/how it reacts to real growth).

As pointed out in the first section of the current Chapter, however, debt, real growth, real interest rates and primary fiscal balances have a more complex relationship than that. Higher debt may have an additional impact on increasing sovereign risk if it negative affects real growth or positively affects real interest rates.

Real interest rates may also add to sovereign risk if they tend to slow growth (via a standard monetary policy shock and its transmission, at least in the short run) and growth may have an impact of either sign on interest rates depending on the circumstances, as reviewed before.

Finally, the effect of fiscal policy action is dependent on its impact on growth (as discussed

Table 2.2: Theoretical effects of fundamentals on sovereign risk (solvency aspect)

Fundamental	SIGN	Rationale	References
Current debt ratio (d)	+	higher initial debt level closer to sustainability limit	tb
Real interest rates (r) on d	+	increases debt ratio through interest expenditure	tb
Real economic growth (g)	-	decreases debt ratio	tb
Primary balance (pb)	-	decreases debt ratio	tb
d effect on pb	-	higher debt forces fiscal adjustment	Bohn, Toth, MO, GKMOQ, AJ
d effect on g	+(?)	an increase in debt level has(?) further impact through lowering growth	GO, WK, RR, Mel (Ége,SV)
d effect on r	+	debt raises interest premium, increases debt service	Edw, Mel, GS
r effect on g	+	an increase in rates slows growth	tb (intertemp), LSZ, BaK, GS
g effect on r	+/-	increase in growth leads to an increase/decrease in interest rates	tb (mon.pol+transmission) / NP, GKK, BeK
g effect on pb	-?	higher growth increases the primary balance, but overall fiscal reaction questionable	GKMOQ, MO, GS, RP, RS, KRV
pb effect on g (inverse fiscal multiplier)	+	an increase in pb decreases growth	Ram, DG, ER, Mel
pb effect on r	-	improvement in fiscal balance reduces interest premia	GO

Sources: author's compilation.

Notes: References in the table are abbreviated as follows.

tb: textbook treatment, Bohn: [Bohn \(1998\)](#), Toth: [Toth \(2011\)](#), MO: [Mendoza and Ostry \(2008\)](#), GKMOQ: [Ghosh et al. \(2013\)](#), AJ: [Afonso and Jalles \(2017\)](#), GO: [Gale and Orszag \(2002\)](#), WK: [Woo and Kumar \(2015\)](#), RR: [Reinhart and Rogoff \(2010\)](#), Mel: [Mellar \(2003\)](#), GS: [Genberg and Sulstarova \(2008\)](#), LSZ: [López-Salido, Stein and Zakrajšek \(2017\)](#), BaK: [Baksa and Konya \(2017\)](#), NP: [Neumeyer and Perri \(2005\)](#), GKK: [Gereben, Karvalits and Kocsis \(2011\)](#), BeK: [Benczur and Konya \(2016\)](#), RP: [Raess and Pontusson \(2015\)](#), RS: [Roubini and Sachs \(1989\)](#), KRV: [Kaminsky, Reinhart and Végh \(2004\)](#), Ram: [Ramey \(2016\)](#), DG: [Dupor and Guerrero \(2017\)](#), ER: [Ellahie and Ricco \(2017\)](#).

by the literature on fiscal multipliers) as well as on real interest rates.

To sum up, the solvency effects of the debt, primary balance, real growth and real interest rate fundamentals that this literature deals with is dependent on the complex relationship between these variables, which are likely to make these effects both non-linear and dependent on the context of the economy in question.

Funding liquidity aspects

Inability to pay is, more profoundly, equivalent to the government not having enough liquid funds to service oncoming debt obligations. There are multiple reasons why such a situation may arise, but the common technical reason is that private investors (and official lenders) are unwilling to lend to the government. Were this not the case, a government that is otherwise willing to service debt would take on future obligations to roll over debt.

Also, such funding liquidity primarily concerns foreign currency debt obligations. Domestic currency obligations could (assuming the government was willing to repay) be funded by the central bank by either directly buying bonds from the government (seignorage), buying from the secondary market or by refinancing the domestic banking sector that buys government securities. Regarding foreign currency obligations, however, central banks may only help the government up to the stock of their (liquid) foreign currency reserves. Therefore reserves should be a key

fundamental factor in this respect.

There are two general reasons why private investors may be unwilling to lend to governments. The first relates to the existence of multiple equilibria in the relationship of default probability and interest rates, which introduces a role for self-fulfilling investor beliefs. The second (partly related to the first) concerns large shocks to prevailing circumstances, notably external (global, regional) liquidity and risk pricing conditions, which will be discussed under the next heading.

As mentioned before, under uncertainty investors will supply funds at interest rates that increase with the probability of default. However, higher interest rates increase the probability of default due to both a willingness to pay aspect (for instance, [Calvo, 1988](#), assumes a government default policy based on debt service costs) or debt sustainability considerations (for example, in [Romer, 2006](#), default arises when stochastic tax revenues turn out to be less than debt servicing funding needs).

This interaction between interest rates and default probability raises the possibility of multiple equilibria. There is always a 'bad equilibrium' in which the market is unwilling to lend at any interest rates²⁰ and therefore default is certain. In usual cases there is at least one 'good equilibrium' in which government receives the needed funds and pays an interest rate that is consistent with a lower (than 1) probability of default. Which of these equilibria plays out depends on what investors believe the rest of the market will do, which leads to self-fulfilling features and the role for creditor coordination just like in the case of bank runs.

This aspect of sovereign credit risk has already been modelled in early papers of [Sachs \(1983\)](#) and [Krugman \(1985\)](#) and these papers also discussed implications about creditor coordination and bailouts.²¹ An often referenced treatment is the model of [Calvo \(1988\)](#).

In the 1990s, the Mexican 'tequila crisis' of 1994 specifically drew attention to this factor, since the Mexican government appeared both willing to pay and solvent, but there was an investor panic with respect to immediate refinancing risk. [Cole and Kehoe \(1996, 2000\)](#) developed a model, in which default is a consequence of both the short maturity of government debt and realization of a random 'sunspot' variable²² that determines which of the multiple equilibria occurs.

[Calvo and Mendoza \(1996\)](#) claimed that the increase in short term dollar obligations and the draining of central bank reserves together triggered the crisis,²³ because the level of reserves

²⁰ As [Krugman \(1985\)](#) notes, above a certain level higher interest rates may increase the probability of default so much that in effect this lowers expected return. This means that even in a stochastic environment there is an upper limit to government borrowing.

²¹ Notably [Sachs](#) (see 1983, pp. 37-40).

²² As noted by several finance papers in case of indeterminacy market rumors play a large role in determining outcomes. The formation of rumors are not explicitly modelled in the literature and are simply taken to be random exogenous shocks, named 'sunspots' to stress their randomness and exogeneity.

²³ A large current account deficit contributed to the decrease of reserves in 1993-1994. The central bank defended the currency band in fear of the adverse effects a large currency depreciation would mean for the economy and the banking sector. The government swapped a significant share of peso-debt into short-term dollar debt, Tesobonos, to signal its commitment to the dollar peg.

eventually became inadequate to preclude a classic speculative run on the currency. [Sachs, Tornell and Velasco \(1996\)](#) also acknowledges the role of some fundamental factors, a large current account deterioration and real appreciation, but argues that it was a sudden shift to a panic regime that caused the crisis in December 1994. Neither did interest rates rise, nor was there much press coverage about Tesobonos prior to December that would have been consistent with a classic balance-of-payments crisis. Like [Cole and Kehoe \(1996\)](#), both [Calvo and Mendoza \(1996\)](#) and [Sachs, Tornell and Velasco \(1996\)](#) stressed the role of multiple equilibria and self-fulfilling features.

Funding liquidity was an important aspect of both the global financial crisis of 2008-2009 and the eurozone sovereign debt crisis of 2010-2012. In the global financial crisis, several emerging market countries that have been shut off from debt markets were also willing to repay their debts, but would have defaulted without international credit lines. In the eurozone sovereign debt crisis, too, several periphery countries resorted to EFSF/ESM programs to fill funding gaps and avoided credit events with the exception of Greece. Other than Greece, all of these experiences show that countries were willing to repay debt obligations and suggest that they would have defaulted without external help.²⁴

Even in the case of Greece that eventually restructured its debt, there were numerous periods in the three years prior to the credit event when investors feared that an 'accidental' or 'hard' default may happen as the country was already shut off from private credit markets, but disbursements and extensions of bailout tranches were subject to difficult negotiations between the Greek government and international lenders. An important point to note is that several elements of these negotiations could have been exogenous for Greece²⁵ and involved significant stochastic elements, which could have contributed to realization of a hard default.

External shocks

A vast literature deals with the transmission of shocks across countries. A large segment concerns non-fundamental components of prices rather than fundamentals, but nevertheless they are important regarding the ability to pay due to both the funding liquidity aspect (external circumstances influence investor willingness to supply credit) and debt sustainability (as the level of interest rates and exchange rate depreciation affect sustainability). Therefore these factors will be briefly discussed here.

²⁴Several papers discuss the implication of the monetary union (and hence the lack of central bank lending-of-last-resort) as a factor, which could have contributed to multiple equilibria and self-fulfilling features (e.g. [De Grauwe and Ji, 2013](#); [Ghosh, Ostry and Qureshi, 2013](#); [Bølstad and Elhardt, 2017](#)).

²⁵For instance popular opinion on lending to Greece in core countries have been external factors in many respects (though partly Greek government actions determined these). The stance regarding the conditionality for bailouts of IMF staff and political leaders of lending countries necessarily also involve subjective elements and judgment calls. Also economic surprises and the ensuing surprises regarding the fiscal outlook was a decisive factor in negotiations. When bad economic news arrived, international lenders necessitated speeding up structural reforms and fiscal consolidation increasing the risk that negotiations could break down and Greece would be left to default. Of course this could then also be viewed as unwillingness to remain in the contract.

I follow the classification of types of financial linkages in [Corsetti, Pericoli and Sbracia \(2005\)](#) and [Giordano, Pericoli and Tommasino \(2013\)](#). These studies refer to *spillover* referring to normal (tranquil) financial interlinkages due to identifiable macroeconomic influences of one country on others; *interdependence* as normal correlations which may be explained or unexplained by fundamentals and *contagion* representing financial linkages that are different from tranquil market behavior. Contagion can be further broken down into *shift-contagion* referring to an unexplained increase in sensitivity to a systemic factor; fundamental-contagion (or wake up call) referring to an increase in sensitivity to macroeconomic variables; and pure contagion to refer to common level shifts in prices which are unrelated to both fundamentals and systemic factors. Consider the specification that extends the specification in [Giordano, Pericoli and Tommasino \(2013\)](#):²⁶

$$S_{it} = \beta_i^0 + \beta_i^1 F_t + \beta^2 Z_{it} + \beta_{ij}^3 Z_{ijt} + D_t(\gamma^0 + \gamma^1 F_t + \gamma^2 Z_{it}) + \epsilon_{it}, \quad (2.7)$$

where S_{it} are sovereign spreads (or their first differences), F_t is a non-fundamental systemic factor, Z_{it} and Z_{ijt} are country- and country pair (e.g trade or interest rate differentials) fundamentals, respectively, and D_t denotes a dummy variable that identifies periods of crisis. In this specification the parameter β_i^1 represents normal co-movements across country spreads related to the systemic factor (interdependence), the parameter β_{ij}^3 represents comovements due to macro-fundamental relationship between countries (spillovers) and β_i^2 is sensitivity to country fundamentals. Contagion-types are distinguished by γ parameters: γ^0 is a common change in all country spreads (pure contagion), γ^1 is an excess sensitivity in crisis to the systemic factor, and γ^2 is an excess sensitivity to country fundamentals (fundamentals-contagion).

The theoretical underpinnings for spillovers are straightforward from standard macroeconomic texts. Business cycle dynamics of countries are linked through trade links and empirically business cycles tend to move together internationally as demonstrated by [Kose, Otrok and Whiteman \(2003\)](#), for instance. There is a theoretical basis for a general effect of financial center (U.S.) interest rates to effect other country spreads due to affecting general liquidity conditions, which may affect pricing. Empirical evidence however has been mixed.²⁷

There is a vast empirical literature that demonstrates strong systemic co-movements (interdependence) among sovereign spreads under normal tranquil conditions as well ([Grandes, 2002](#); [Ang and Longstaff, 2011](#); [Kocsis, 2014](#), to name a few). Normal systemic co-movements may be due to both fundamental factors (global business conditions, U.S. monetary policy) that are not well captured by fundamental proxies included in the specification or they may be due to general global liquidity conditions and risk aversion (see [Augustin, 2014](#), for references).

²⁶[Giordano, Pericoli and Tommasino \(2013\)](#), equation 2, p.141.

²⁷Higher US interest rates have been found to increase sovereign spreads in several papers ([Dailami, Masson and Padou, 2008](#); [González-Rozada and Yeyati, 2008](#); [Hilscher and Nosbusch, 2010](#)), but had negative coefficients in others ([Eichengreen and Mody, 1998](#); [Andritzky, Bannister and Tamirisa, 2007](#); [Benczúr and Ilut, 2016](#)) or were varied across specifications ([Ferrucci, 2003](#); [Fender, Hayo and Neuenkirch, 2012](#)).

Contagion of either type may be due to various theoretical reasons. Usually these entail weak fundamentals, but are highly dependent on non-fundamental factors. [Calvo and Mendoza \(1996\)](#) and [Calvo and Mendoza \(2000\)](#) claim that increasing globalization of investor portfolios makes it relatively costly to acquire information on fundamentals, which increases the role for rumors and herding. This results in a significant segment of the market choosing not to acquire costly information but rather mimic other trader portfolios. There is a group of informed investors specialized in information acquisition, but since this group is leveraged, liquidity shocks may force them to provide signals that do not match their information on fundamentals. Misinterpretation of these shocks causes non-fundamental contagion. [Chari and Kehoe \(2003\)](#) discusses herding effects due to uninformed investors reacting immediately to even small price signals without waiting for more information, which would be needed for prices to reflect fundamentals better.

Other papers consider models, where contagion can happen with or without a fundamental basis. [Kodres and Pritsker \(2002\)](#) discusses a model with rational expectations and asymmetric information, when contagion is a result of portfolio rebalancing by global investors due to either fundamental-related or nonfundamental related shocks. [Chang and Majnoni \(2002\)](#) provides a model where sunspots are independent across countries and where purely expectational contagion can still occur, when investors cannot decide whether the initial crisis was due to a sunspot or fundamentals. [Allen and Gale \(2000\)](#) models financial contagion rooted in the liquidity preference of common creditors, who diversify their portfolio to take advantage of the fact that liquidity shocks are imperfectly correlated across regions. This leads to banks having inter-regional claims, which insure idiosyncratic risks. However this linkage itself leads to financial contagion when there is a large enough shock in one region that takes up overall liquidity for a common creditor.

A recent finding by [Fülöp and Kocsis \(2018\)](#) based on textual information in financial news is that even global risk aversion proxies, such as the VIX index have a substantial fundamental component. This supports the case for expectations about future fundamentals (or its tail risk scenarios) being important in asset prices proposed by [Benzoni et al. \(2015\)](#) and [Augustin and Tédongap \(2016\)](#).

Table 2.3 summarizes the liquidity aspects of the fundamentals - sovereign risk relationship. Financing liquidity risk may arise if the amount of short term FX funding needs (due to either maturities or current account deficits) are large relative to FX reserves of the central bank and international official assistance is also questionable. Then rumors may be enough to spark a self-fulfilling speculation on a lack of funding.

In terms of domestic debt obligations the central bank is usually available as a lender of last resort. However, in a monetary union this may not be the case ([De Grauwe and Ji, 2013](#)) and hence, domestic-currency funding needs (maturing debt and primary deficit) become important determinants.

Political uncertainty and fundamentals related to debt sustainability aspects (as well as external factors) may also determine probabilities/outcomes of whether a good or bad funding

Table 2.3: Theoretical effects of fundamentals on sovereign risk (liquidity aspect)

Fundamental/Factor	SIGN	Rationale	References
short-term FX debt	+	large oncoming FX debt obligations may ignite rumors that other investors are withdrawing lending leading to failed auctions and self-fulfilling beliefs	CM, CK
current account/trade balance	-	large deficits imply large FX financing need	Kru, CM, STV, CK
FX reserves	-	large oncoming FX debt obligations can at worst be financed by reserves	CM
possibility of international bailout	-	... or international assistance	BE
short-term domestic debt	+	large oncoming domestic funding needs may lead to failed auctions through self-fulfilling beliefs	DJ
fiscal deficit	+	large oncoming domestic funding needs may lead to failed auctions through self-fulfilling beliefs	DJ
possibility of central bank lender-of-last-resort help	-	large oncoming domestic funding needs may at worst be financed by the central bank	DJ
political uncertainty	+	may ignite rumors about willingness to pay	Sachs, STV, Pas
debt sustainability	+	may ignite rumors that other investors are withdrawing lending leading to failed auctions and self-fulfilling beliefs	Kru, Sachs
adverse spillovers	+	global shocks (business cycle or interest rate changes in financial centers) could reduce demand for government assets (liquidity aspects) and increase spreads	DMP, RY, HN
contagion: risk repricing	+	global liquidity shocks, wake-up calls, sunspots may lead to adverse risk repricing	CKMM, GPT

Sources: author's compilation.

Notes: References in the table are abbreviated as follows.

CM: Calvo and Mendoza (1996), CK: Cole and Kehoe (1996), Kru: Krugman (1985), STV: Sachs, Tornell and Velasco (1996), BE: Bølstad and Elhardt (2017), DJ: De Grauwe and Ji (2013), Sachs: Sachs (1983), Pas: Paserman (2017), DMP: Dailami, Masson and Padou (2008), RY: González-Rozada and Yeyati (2008), HN: Hilscher and Nosbusch (2010), CKMM: Corsetti, Pericoli and Sbracia (2005), GPT: Giordano, Pericoli and Tommasino (2013).

liquidity equilibrium materializes.

2.2.5 Political economy considerations

Political economy motives primarily influence the willingness to pay aspect of sovereign credit risk. However several papers have emphasized how uncertainty due to political risks changes investor behavior, which may affect funding liquidity and debt sustainability aspects, therefore I will discuss these motives here, separately.

Several considerations may influence perceived benefits and costs of debt repudiation from a political economy perspective.

Baldacci, Gupta and Mati (2008) considers a simple model, where governments have a political reputation they care about, which therefore enter as a cost of default. When political risk rises, reputation is reduced and there is a smaller loss at stake when repudiating debt: default probability increases.

Eichler (2014) considers a host of political and institutional factors that may have an influence on sovereign risk: including democratic/autocratic regimes, presidential/parliamentary political systems, political stability, closeness of elections, partizanship, quality of governance. Empirical estimation reveals that low quality of governance and parliamentary systems contribute significantly to higher spreads, whereas political instability has an adverse effect in au-

ocracies, but not in democracies. Other factors are found to be insignificant.

Default also means a wealth transfer from bondholders to future taxpayers. Governments may naturally be assumed to care about domestic lenders more than foreign lenders, so defaults are also more likely when more public debt is held abroad. A factor to consider here is whether governments can discriminate between domestic and external borrowers in default. [Asonuma and Trebesch \(2016\)](#) found that historically, governments could not make such a distinction. Therefore, governments do have to consider what the consequences of defaulting would entail, notably regarding the balance sheet of domestic bondholders and how this could reverberate in the economy.

Full debt writedowns may lose their appeal when a significant share of bonds are held by local residents. [Reinhart and Rogoff \(2011a\)](#) argue that domestic debt has been a significant factor throughout history and is the missing link to explain the observed low external debt levels when countries default. [Broner et al. \(2014\)](#) predict that when crisis hits, foreign bondholders will sell their assets to residents. [Brutti and Sauré \(2016\)](#) find support for this view in the eurozone sovereign crisis.

Regarding domestic wealth transfers [Song, Storesletten and Zilibotti \(2012\)](#) elaborates on the redistribution between generations: lenders are older than future taxpayers so default favors the latter. Redistribution effects can be considered between societal layers, which may depend on the ideology (partizanship) of government: how much it prefers wealth to be redistributed from typically more wealthy bondholders to typically less-well-off middle-class taxpayers ([Hatchondo and Martinez, 2010](#); [Scholl, 2017](#)). [D'Erasmus and Mendoza \(2016\)](#) explore the implications of a model in which the government considers the utility of high- or low-wealth social layers with different weights. In this setting domestic debt issuance as well as debt defaults have a redistributive incentive.

Finally politicians themselves may consider their individual political careers and may decide against bringing the default decision based on this factor ([Borensztein and Panizza, 2009](#)).

These considerations may all shift the balance of costs and benefits considered only from an economic perspective.

Several recent papers considered the effect of uncertainty or ambiguity on sovereign spreads. [Paserman \(2017\)](#) for instance argued that ambiguity-averse investors command higher premia for bonds of more corrupt governments, because corruption proxies availability of information and ambiguity. [Pástor and Veronesi \(2013\)](#) modelled uncertainty deriving from new government policies and showed that premia associated with such uncertainty would rise especially under weak economic conditions. Other papers argued that inefficient policy communication could contribute to uncertainty and higher spreads ([Collignon, Esposito and Lierse, 2013](#); [Mohl and Sondermann, 2013](#)). [Huang et al. \(2015\)](#) claimed that international political risk enters into the systemic component of sovereign spreads.

2.2.6 Conclusions: which fundamentals are theoretically important?

To conclude this section, I briefly review some of the most important insights of the theoretical literature on the relationship between sovereign credit risk and its fundamental determinants.

As seen in Tables 2.1-2.3 the literature proposed and discussed effects of many domestic fundamentals from both the *willingness to pay* and *ability to pay* aspects of sovereign credit risk.

One of the central fundamentals in both of these aspects has been the debt ratio. An increase in debt is thought to raise sovereign risk via increased motivation to consume the amount to be repayed (willingness), via pushing debt towards levels considered unsustainable (ability: solvency) and via interest payments and redemptions raising the current financing need (ability: liquidity). Effects of debt on other fundamentals such as growth and interest rates are also more likely to add to the adverse impact on sovereign credit risk. However the effect could vary significantly due to interaction with other factors: the willingness to repay may be influenced by who holds the debt (external/domestic residents, those that are more/less important for government in power, how much is held by financial intermediaries and how important this sector is for the economy), whereas the term structure and denomination of debt could be important from the ability to repay perspective.

Real economic growth is inversely related to sovereign risk based on both willingness and ability to repay considerations. Higher interest rates on debt raise sovereign risk as they reduce the motivation to repay and raise debt and oncoming financing needs. However the empirical relationship of these variables to sovereign risk proxies may be complicated by non-linearities and effects on other variables. For instance, higher growth may improve primary balances, trigger inflation (decreasing real interest rates), but may also lead to a tightening of monetary policy (increasing real interest rates) and the reaction of domestic actors to increased income is also important in the overall outcome on sovereign risk (whether it is spent, and how much on imported goods or rather saved) the background of which may be the perception of how temporary/lasting the growth improvement is.

The current account is an endogenously determined fundamental in quantitative models and due to consumption smoothing it is often predicted to improve in upturns making it move inversely with sovereign risk. However, the current account of emerging markets is empirically observed to improve in downturns as capital flight is experienced, whereas it tends to deteriorate in upturns as investors are more willing to lend in these times. The current account deterioration also means an increase in external indebtedness and higher foreign-currency financing needs by which tokens it increases sovereign credit risk.

Official reserves are both useful in lowering concerns about foreign currency funding liquidity and high reserves also increase potential sanctions and costs of default, all these factors acting to reduce sovereign risk. However, the magnitude of these effects are dependent on whether foreign currency liquidity needs are important at all and whether coordination of sanctions are

plausible.

All in all, theory is useful to identify important channels and types of effects of fundamentals on sovereign credit risk. However theory also points out the many ways fundamentals are interrelated with each other in complex, often non-linear relationships. Based on these interrelationships and non-linearities, partial effects of fundamentals are expected to vary by the given context. This makes it probable that fundamental effects will also vary in time.

CHAPTER 3

Measures of sovereign credit risk

Sovereign credit risk is the expected loss that an investor faces as a percentage of investments in sovereign bonds due to the possibility of a sovereign credit event. Expected loss is the product of the probability of the credit event and the loss given the credit event.

This chapter derives how such expected losses are related to three key proxies of sovereign risk: credit ratings (on foreign-currency long-term issuances), spreads on foreign currency bonds compared to yields on same maturity risk-free bonds (bond spreads, from here on) and sovereign CDS spreads.

3.1 Credit ratings

Credit rating agencies have the core objective of providing ratings that describe the relative creditworthiness of issuers. There are however two important factors that cause credit ratings not to connect with default probabilities in a straightforward way. First, ratings are measured on an ordinal scale and the definitions of grades in these scales are vaguely defined in terms of default probabilities. Second, ratings are not timely assessments of credit risk, because agencies aim to balance between rating stability and rating precision. These are elaborated in turn.

The three main rating agencies considered in the thesis (Moody's, Standard and Poors' and Fitch Ratings) use a 16-20 notch scale to assess the long-term default probability of issuers. The scale has letter grades running from Aaa/AAA to C/C-CCC as credit quality declines, and letter grades have three modifiers (+/ - in case of S&P and Fitch and 1/2/3 in case of Moody's).¹ These notches are however only vaguely defined in terms of their relation to credit risk as the definitions are qualitative in nature.²

Nonetheless credit rating agencies periodically publish empirical cumulative default frequencies for rating notches and these can be used to give a more quantitative assessment to ratings.³ These publications reference historical relationships which may change over time. In

¹Although S&P and Fitch ratings are differently noted compared to Moody's and there are differences among agencies at the highest risk end of the scale, qualitative definitions of rating grades and their consistency with credit spreads show that these scales are in fact closely aligned (see [Hill, Brooks and Faff, 2010](#), for a detailed analysis that assesses differences across agencies).

²For example, Standard and Poor's AAA notch is defined as "The obligor's capacity to meet its financial commitments on the obligation is extremely strong". The definition for the AA, A grades replaces "extremely strong" with "very strong" and "still strong" ([Standard & Poors', 2017](#)). Moody's defines the obligations rated at the respective first three grades, Aaa, Aa and A, as "highest quality, with minimal risk", "high quality and subject to very low credit risk" and "upper-medium grade and subject to low credit risk" ([Moody's, 2018](#)).

³The cumulative default frequency measures the overall fraction of defaulted entities to all entities in a given time frame. This can be broken down into the cumulative default frequency component of a first part of this period and the default frequency of the entities that have not defaulted in the first subperiod, but default in the remaining

case of sovereigns, the small number of rated entities precludes any meaningful statistical analysis of the time-variation in the rating – default probability relationship, but long-term historical default frequencies of rating notches and rating transitions (the probability of moving from one notch to the other) can be used to construct a proxy of empirical default probability for each notch. Such proxies confirm that worse ratings are consistent with higher default probabilities.

Figure 3.1: 5-year cumulative default probabilities vs ratings

Sources: author's compilation based on rating transition matrices: [Moody's \(2017\)](#), [Standard & Poors' \(2018\)](#) and [Fitch Ratings \(2016\)](#).

Notes: Letter grades (S&P, Fitch scale) versus 5-year cumulative default probabilities calculated based on transition matrices.

Since rating notches are qualitative constructs of rating agencies, there is absolutely no theoretical reason to expect rating notches to be equally spaced in terms of default probabilities. However, in practice, logarithmic default probabilities versus a simple linearized rating scale do closely fit a linear line and they are also very much comparable across agencies. This is shown in Figure 3.1.

In Chapter 8, I investigate the relationship between rating notches and default frequencies and find that a logistic specification gives a better description of the relationship than both the linear and logarithmic specifications.

period of the time frame. The share of non-defaulters in the first period is called the survival rate and the fraction of defaults in the second period is the hazard rate. The cumulative default rate is therefore the first period cumulative default rate plus the first period survival times the second-period default rate. If the cumulative default rate is broken down recursively into infinitesimally small time periods, this outlines a path for the instantaneous hazard rate.

Besides the question of the proper functional form, the other difficulty for matching default probabilities and ratings is that ratings are not timely measures of default risk. Several empirical papers point out the predictability of ratings by both credit spreads and past ratings, which suggests that ratings do not incorporate all available information on credit risk.

References provided in [Altman and Rijken \(2004\)](#) also show that credit rating agencies purport the persistence in ratings to the objective of 'rating stability' and their 'through-the-cycle' methodology. Rating stability is intended to help market participants that would incur larger transaction costs if they were to base their investment policies on ratings that frequently changed. Due to these objectives, agencies tend to change ratings when oncoming information is already sufficient to significantly change their long-term assessment of default risk. A manifestation of this is using multi-year averages in case of some indicators [Vidovics-Dancs et al. \(2019\)](#). This leads to a trade-off between rating precision and rating stability. Agencies choose to ignore smaller changes in fundamentals, giving up precision in favor of stability. [Pennartz and Snoeij \(2012\)](#) find that of the three major agencies Moody's tends to prioritize ratings stability the most, whereas S&P tends to be the most precise.

Preference for stability explains the persistence of rating levels in general and it also explains why ratings may lag credit spreads. However it does not explain autocorrelation of rating changes (rating momentum), which is also a well-documented feature in the literature. For example [Al-Sakka and ap Gwilym \(2009\)](#) find that rating downgrades are significant predictors of future downgrades in the case of major agencies. [Altman and Rijken \(2004\)](#) also supports the case for serial correlation in rating transitions even after controlling for the effects of long-term horizons of agencies. While [Cruces \(2006\)](#) also corroborates findings of autocorrelation, he argues that part of the predictability of ratings could stem from the predictability (mean reversion and local trends) of default probabilities themselves. The predictability of ratings by credit spreads ([Larraín, Reisen and Von Maltzan, 1997](#); [Kou and Varotto, 2008](#)) suggest that ratings are lagged and only partially contain available creditworthiness information.

Despite these difficulties, rating scales are consistent with default probability ranking as empirical default frequencies (and long-term frequencies using transitions) are monotonically increasing as credit rating deteriorate. Ratings are also explained by fundamentals relevant for creditworthiness (many of the ones listed in the previous chapter) as found by a number of studies beginning with [Cantor and Packer \(1996\)](#) (e.g. [Afonso, 2003](#); [Borio and Packer, 2004](#); [Rowland, 2004](#)).

In fact, partly due to stricter regulations of the industry since the financial crisis, rating agencies are now fairly transparent about details of their methodologies regarding the assignment of ratings. A useful summary of these methodologies are given in [Ligeti and Szörfi \(2016\)](#). Table 3.1 is adapted from their study, which shows the various fundamental factors that the three agencies take into account.

Table 3.1: Fundamental determinants of credit ratings

Fitch				
Economic assessment	Fiscal assessment	Structural features	External finances	
Real GDP growth Real GDP growth volatility Inflation	Fiscal deficit Public debt Interest payments Public foreign currency debt	Money supply GDP per capita Government effectiveness Status of reserve currency Years since last default	Commodity dependence Current account balance plus net foreign direct investment Gross external debt of the general government External interest service Foreign exchange reserve	
Moody's				
Economic assessment	Fiscal assessment	Institutional assessment	„Event” risk	
Real GDP growth Real GDP growth volatility WEF Global Competitiveness Index Nominal GDP GDP per capita <i>Diversification</i> <i>Credit boom</i>	Public debt Debt burden Debt trend <i>General government FX debt/General government debt</i> <i>Other public sector debt</i> <i>Public sector financial assets</i>	Government effectiveness Inflation Inflation volatility <i>Track record of default</i>	Domestic political risk Geopolitical risk Gross borrowing requirements Non-resident share of general government debt Market implied ratings Baseline Credit Assessment (BCA) Total domestic bank assets/GDP Banking system loan-to-deposit ratio Current account balance + FDI External vulnerability indicator Net international investment position	
S&P				
Economic assessment	Fiscal assessment	Institutional effectiveness	External assessment	Monetary assessment
GDP per capita <i>GDP per capita trend growth</i> <i>Diversification</i> <i>Credit boom</i>	Change in general government debt Net general government debt Interest payment <i>General government liquid financial assets, volatility of revenues</i> <i>Foreign currency government debt, remaining maturity</i> <i>Non-resident share of general government debt</i> <i>Flexibility of tax regime</i> <i>UN development index</i> <i>Demography</i> <i>Other public sector debt</i> <i>Sovereign exposure of banking sector</i>	Effectiveness, stability, predictability and transparency of policymaking and political institutions <i>Geopolitical and external security risk</i> <i>Debt payment culture</i>	Status of reserve currency Local currency in circulation <i>Current account balance</i> <i>Net international investment position</i> <i>International terms of trade</i>	Exchange rate regime Credibility and effectiveness of monetary policy Inflation Real exchange rate stability Level of financial intermediation credit market

Source: Adapted from Ligeti and Szörfi (2016, Table 2, p 18).

3.2 Sovereign credit spreads

This section deals with two key market proxies of sovereign credit risk, the yield spread of hard currency⁴ sovereign bonds on risk-free benchmark bonds (henceforth, bond spreads) and premia

⁴The reason why hard currency (in effect, US dollar and euro) denominated bond yields offer a more straightforward assessment of credit risk is that comparing to the US Treasury rates or German Bund yields in this case

paid by sovereign protection buyers in the CDS market (CDS spreads).

The intuition for the link between these spreads and sovereign credit risk is straightforward. The sovereign promises to pay coupons and the notional at maturity on sovereign bonds. If a default occurs, however, investors receive only a fraction (the recovery rate, RR) on their investment. A comparable risk-free bond on the other hand is certain to repay the notional and coupons, so the yield spread on sovereign bonds is required to compensate investors for choosing the risky bonds instead of risk-free securities. In the case of credit default swaps, the protection buyer offers to pay the CDS premium in exchange for receiving the loss on defaulted bonds ($h = 1 - RR$) in case a default occurs. The CDS spread needs to be high enough to compensate the protection seller for the risk of payment, i.e. the probability of default and the loss on bonds given a default.

In finance, the two main approaches to pricing credit risk are due to structural and reduced form default models. Structural models follow the corporate literature along the lines of [Merton \(1974\)](#). In these corporate credit models, the probability of the firm asset value falling below the debt threshold (or the equity value falling below zero) is calculated from an assumed dynamic process for the asset value. When equity becomes negative the firm becomes insolvent and it is liquidated in this case as a result. Merton-type models assume a lognormal price for the asset value, in which case closed-form formulas are available for the bond price. These models therefore assume that there is a stochastic variable and a threshold, which if reached, default necessarily occurs.

The idea is not straightforward to incorporate in the analysis of sovereign credit risk, however, because there are no natural candidates for the value function, its dynamics or the threshold. Nevertheless, there have been several papers in the sovereign literature that endeavored to use the structural framework. [Weigel and Gemmill \(2006\)](#) assume the value as a latent signalling variable about the sovereign creditworthiness, which is estimated by filtering methods. Fundamentals are related to the signalling variable, but only ex post, therefore it is difficult to view this approach as structural: a structural model would set observables as drivers of the value a priori based on theory. [Clark and Kassimatis \(2011\)](#) assume a value function based on items in the national accounts, specifically, net exports plus consumption minus wages and [Clark and Kassimatis \(2015\)](#) apply these values to sovereign credit risk. However, it is not clear why such macroeconomic aggregates if they reached the threshold of the debt level would result in the sovereign defaulting. [Plank \(2010\)](#) instead identifies the sovereign value as net exports plus international reserves and the threshold for default are related to outstanding external debt. This paper therefore identifies sovereign distress due to an inability to pay (a foreign exchange liquidity) aspect. Although these fundamentals are undoubtedly important in creditworthiness it can be objected that sovereign defaults often involve a willingness to pay aspect. Moreover, in case

the yield spread is primarily the result of credit risk differences (and risk premia and liquidity factors, as discussed below), whereas comparing to local currency yields would also include the effects that exchange rate expectations, different inflation expectations in the two currencies and different monetary policy stance have on spreads.

of abundant international liquidity and otherwise sound country fundamentals, investors would probably refinance the sovereign and thus a default could be averted even if the value is below threshold. Even though [Genberg and Sulstarova \(2008\)](#) is not a structural model, it is organized around the same line of thought, as the probability of default here is assessed as the probability of the debt ratio reaching a threshold level subject to estimated autoregressive processes of its determinants, the primary fiscal balance, the real interest rate and the real GDP growth rate.

The sovereign credit risk model presented in the theoretical part of the thesis is also close in spirit to these types of models as it also defines a value variable (based on the sovereign willingness to pay) and a threshold for defaulting (Chapter 5) and analyzes the dynamics of the value function to assess the default probability with respect to fundamental parameters (Chapter C.2).

Reduced form models of default instead assume a process for the default intensity (λ_t , the instantaneous hazard rate at t) itself without reference to underlying drivers of the default and a process for the risk-free interest rate r_t^f .

Based on [Lando \(1998\)](#)⁵ the price of a zero-coupon bond with time to maturity τ and payoffs of 1 in case of no default and $1 - h$ in case of default has a price:

$$P_t = E_t^Q \left[e^{-\int_t^{t+\tau} r_s^f + \lambda_s ds} \right] + E_t^Q \left[\int_t^{t+\tau} (1 - h) \lambda_s e^{-\int_t^s r_u^f + \lambda_u du} ds \right] \quad (3.1)$$

under the risk-neutral (martingale) measure, Q , where r^f stands for the default-free interest rate.

The first term in the expression quantifies the expectation of the no-default payoff unit payoff, which is a continuous time discount factor that discounts by the risk-free rate and the probability of a default. The second term refers to the payoff of $1 - h$ in case of the default. The first integral in this term accounts for the stochastic nature of the arrival time, when the default occurs (running from t to maturity) and the second integral is again the same form of discount factor (which runs from t until the stochastic time of default).

The economics strand of the sovereign credit risk literature uses the simpler *effective yields* instead of the *logarithmic yields* (continuous compounding) prevalent in the finance strand for pricing. The economics strand also customarily simplifies defaults to occur at discrete time intervals which contrasts the above formula, where default is seen to occur anywhere. The approach of the finance strand is more sophisticated and better approximates real prices, but the difference between the two approaches is small in practice with the exception of few periods of

⁵[Duffie and Singleton \(1999\)](#) has a simpler formulation in which the loss on bonds are defined in terms of the prevailing market price. In that formulation:

$$P_t = E_t^Q [e^{-\int_t^T R_s ds}], \quad R_t = r_t^f + \lambda_t h.$$

I present the derivation in [Lando \(1998\)](#), because in the thesis I use the haircut on bonds in terms of the notional, not the market price.

extreme yields and very high default probabilities.

In the thesis, I follow the economics strand of the sovereign credit literature and consider a one-period bond of one-year maturity. Then, the one-period bond that can only default at the end of the period and with a risk-free alternative that is also a zero-coupon bond that has a unit payoff at $t + 1$, the zero-coupon bond price in t reduces to:

$$P_t = E_t^Q \left[\frac{1 - \lambda_{t+1}}{1 + r_t^f} + \frac{(1 - h)\lambda_{t+1}}{1 + r_t^f} \right] = \frac{1 - E_t^Q [\lambda_{t+1}h]}{1 + r_t^f}. \quad (3.2)$$

Since the yield on the zero-coupon bond is $r = 1/P - 1$, and it is also the risk-free rate plus the yield spread, S_t , we can write the following expression:

$$\frac{1}{1 + r_t^f + S_t} = \frac{1 - E_t^Q [\lambda_{t+1}h]}{1 + r_t^f}$$

so that

$$\begin{aligned} 1 + r_t^f &= (1 - E_t^Q [\lambda_{t+1}h])(1 + r_t^f + S_t) \\ &= (1 - E_t^Q [\lambda_{t+1}h])S_t + (1 + r_t^f) - E_t^Q [\lambda_{t+1}h](1 + r_t^f) \end{aligned}$$

from which we get the spread:

$$S_t^{BOND} = \frac{E_t^Q [\lambda_{t+1}h]}{1 - E_t^Q [\lambda_{t+1}h]}(1 + r_t^f). \quad (3.3)$$

Within this setting the spread and default risk (the probability times loss given default) have a logistic functional relationship. When either the default probability or the loss on bonds converge to zero, so does the spread. When both the default probability and the loss on bonds converge to one, the spread becomes infinite. The term with the risk-free interest rate is usually very close to one and thus variation in the risk-free has a negligible direct effect on spreads (it can have a non-negligible effect through affecting λ).⁶

The influential paper of [Edwards \(1983\)](#), which determined the functional form in later empirical papers for decades, assumed a relationship between the spread and the probability of default similar to equation (3.3) referring to the model of [Feder and Just \(1977\)](#): $S = \lambda/(1 - \lambda)A$, with the A term containing the expected loss, h , an element related to investor demand elasticity and the inverse of the funding cost. Note that a key difference is that h is a multiplicative factor,

⁶There are various forms of the spread derived in the literature with the heterogeneity stemming from different assumptions on the recovery and the coupon payment of the sovereign bond.

Equation (3.3) can be further simplified to $S_t = \lambda_{t+1}h(1 + r_t^f)$ with the assumption of the sovereign defaulting only on the principal and always repaying the interest on one-period coupon bonds (e.g. [Benczur, 2001](#)). In this case the spread and default intensity have a log-log functional form rather than the logistic form above.

Some papers arrive to equation (3.3) above, but simplifying by assuming a full debt repudiation (e.g. [Dailami, Masson and Padou, 2008](#)).

Most papers in the quantitative literature do not derive spreads explicitly, but use the zero-coupon bond price as given in equation 3.2 and often drop h by assuming full debt repudiation.

resulting in a simpler form than in equation (3.3). [Edwards \(1983\)](#) also assumed a logistic form for the probability of default in terms of fundamentals, then $\lambda = e^{bX}/(1 + e^{bX})$ and so $\lambda/(1 - \lambda) = e^{bX}$. Substituting this in equation (3.3), one gets the log-linear relationship between spread and fundamentals that has been used in much of the emerging markets empirical literature:

$$\ln S_t^{BOND} = bX_t + \ln(1 + r_t^f).$$

In case of CDS spreads no-arbitrage pricing requires the present value of the expected payoffs of the protection buyer and the protection seller to be equal for new contracts. Following the exposition in [Pan and Singleton \(2008\)](#), the premium leg of an M-year contract with semiannual premium payments⁷ has a present value of

$$1/2S_t^{CDS} \sum_{j=1}^{2M} E_t^Q \left[e^{-\int_t^{t+j/2} r_s^f + \lambda_s^Q ds} \right],$$

which sums up the CDS premium payments each multiplied with the discount factor seen before. The discounting serves the purpose to cumulate the alternative cost of the risk-free investment (integration by r^f) and the probability of not observing a default (surviving) until the next payment (integration by λ).

The protection leg has the present value

$$(1 - RR^Q) \int_t^{t+M} E_t^Q \left[\lambda_u^Q e^{-\int_t^u r_s + \lambda_s^Q ds} \right] du,$$

where, again, the first integral assesses the default probability for the duration of the contract and the second integral discounts the payment of $1 - RR$ if a default occurs.

Combining the two legs gives the risk-neutral CDS spread:

$$S_t^{CDS} = \frac{2(1 - RR^Q) \int_t^{t+M} E_t^Q \left[\lambda_u^Q e^{-\int_t^u r_s + \lambda_s^Q ds} \right] du}{\sum_{j=1}^{2M} E_t^Q \left[e^{-\int_t^{t+j/2} r_s^f + \lambda_s^Q ds} \right]}, \quad (3.4)$$

Again in the one-period (annual) *effective yields* setting that conforms with the economics strand of the literature, where only one premium payment is made conditional on the sovereign not defaulting at the end of the period, the premium leg is $S_t^{CDS}/(1+r_t^f)$ ⁸, whereas the protection leg is $E_t^Q [\lambda_{t+1}h]/(1+r_t^f)$ and so the spread can be written as:

$$S_t^{CDS} = E_t^Q [\lambda_{t+1}h]. \quad (3.5)$$

⁷This derivation assumes independence of the risk-free rate and default probability. Corrections for the empirically observed correlation are shown in [O'Kane \(2011\)](#) to be very small in magnitude.

⁸In a CDS contract, when default occurs the accrued premium is paid out. Without this condition the payment would be $(1 - \lambda)S_t^{CDS}/(1 + r_t^f)$.

Note the differences compared to the bond spread. First, because a CDS contract pays out the accrued premium in a default, whereas a sovereign defaulting on the bond would pay the recovery rate on the spread, therefore the premium leg is larger. Also, since both the premium payments and protection payments are discounted at the same rate, the risk-free rate does not appear in the CDS premium. Note that in empirically relevant cases $1 - \lambda_{t+1}h$ and $1 + r_t^f$ are close to one and so the CDS spread closely approximates bond spreads.

3.2.1 Risk premia in sovereign credit spreads

Above derivations dealt with the risk-neutral pricing of CDS and bond contracts. There are several factors due to which observed market pricing can deviate from true expected default risk, which therefore gives rise to risk premia within sovereign spreads.

The empirical finance literature documented several important features of sovereign spread risk premia. First, risk premia were generally found to be positive and to make up a substantial part of sovereign spreads (Pan and Singleton, 2008; Remolona, Scatigna and Wu, 2008; Longstaff et al., 2011). Second, risk premia have been shown to be volatile and to have a strong common component, i.e. risk premia in both risky bonds and CDS spreads display high positive cross-country correlations (Pan and Singleton, 2008; Longstaff et al., 2011; Horvath et al., 2014a; Kocsis and Nagy, 2011). Third, risk premia on bonds and within CDS spreads have been found to be correlated with proxies of returns in other asset classes and with more general indicators of risk pricing (i.e. with the VIX index and the US corporate high yield spreads). Ang and Longstaff (2011) interpret the strong commonality and comovement with global financial risk indices as evidence that risk premia are determined by financial markets rather than domestic macroeconomic fundamentals. While Fülöp and Kocsis (2018) do not break down sovereign spreads into risk-neutral and risk premium components, their results suggest that much of the variation in sovereign spreads that is linked to the common global factor is in fact determined by volatile expectations about future (global) fundamentals. This is consistent with the idea of fragile beliefs of investors regarding the economic outlook (Benzoni et al., 2015).

By standard arguments in asset pricing (e.g. Cochrane, 2009; Hull, 2009), investors command a premium to compensate them for covariance of investment returns with the overall market return on the risky market portfolio and more generally their consumption (as the market portfolio return is also correlated with consumption). An investment that has higher payoffs in bad times (negatively correlates with the market) is attractive, because it can be used to diversify the risk of the portfolio. It will have high returns when marginal utility of consumption is high, i.e. when an incremental increase of consumption is more highly valued. Therefore such an investment will have a higher price and will offer a lower return than calculated simply based on its expected return. In contrast, investments that positively correlate with the market will have to pay a premium on the risk-neutral spread. This spread compensates investors for the expectation that the investment payoffs will be low exactly at the wrong time, i.e. when market

returns are also low and marginal utility of consumption is high.

As mentioned above, both the holding of risky bonds and selling protection on CDS spreads are investment positions whose return correlates positively with the general market. Regarding bond markets, this means that as equity markets globally lose value and risk indicators increase the prices of risky bonds decrease, both corporates and sovereigns. As the prices of fixed income assets decrease, their spreads vis-a-vis the risk-free interest rate rise. This positive correlation commands an extra premium so that more risky bonds that have higher spreads compared to the risk-free benchmark have their spreads increased even further.

Similarly, CDS spreads tend to generally rise, when spreads on risky bond prices increase. In times of financial market stress, past sellers of CDS protection book a loss, both because new contracts would offer higher premia on the same entity and thus the value of existing contracts (viewed from this side) loses value and default risk itself increases, whereas the CDS premium fixed in the past contract remains the same. Therefore CDS protection sellers require a risk premium to be compensated for the adverse correlation with market returns and thus contractual CDS spreads are set higher than necessary based on the default risk of the reference entity alone.

The size of these market risk related premia may be larger due to the fact that in bad times, correlation between assets tends to increase.

As mentioned in the previous chapter, [Sunder-Plassmann \(2018\)](#) found that recovery rates tend to positively correlate with economic output. Therefore variation in the recovery rate may also command a risk premium because holders of bonds would face larger losses in bad states of the world, exactly at times when they value marginal returns the most.

A segment of the literature on advanced country bond spreads discussed liquidity premia within bond spreads ([Beber, Brandt and Kavajecz, 2008](#); [Manganelli and Wolswijk, 2009](#); [Favero, Pagano and Von Thadden, 2010](#)). Liquidity has several (disparate) definitions, but the key idea is that when a market is illiquid then selling large quantities of bonds within a short time frame are only possible at a loss, as market makers will adjust their prices downwards. Note that liquidity considerations can interact with the market risk premia above, as liquidity shocks are positively correlated with bad states of the world. The studies referred to by [Hull, Predescu and White \(2005\)](#) estimate the size of the liquidity component to be in the 10-35 basis points range. Based on these estimates liquidity could be a significant determinant of only high grade issuers.

These two (market risk and liquidity risk) views of the risk premia are the most prevalent, although several alternative explanations also exist as to why spreads are larger than implied by default risk alone. [Hull, Predescu and White \(2005\)](#) argue that the US Treasury rates used as risk-free benchmarks may themselves be bad proxies of the risk-free rate, because various regulatory requirements and tax incentives could offer a discount on their yields. Also related to this point, in recent years, structural demand may also have become more important components within bond spreads as central banks bought significant amounts of risk-free government securities in quantitative easing programs ([Horváth et al., 2014b](#)). This additional demand could have depressed yields on advanced country government bonds and this could have been a factor acting

to increase bond spreads.

Another factor could be that bond portfolios are hard to diversify, because bond returns have a very skewed distribution ([Amato and Remolona, 2003](#)).

Still another theory, advanced by [Janus, Jinjarak and Uruyos \(2013\)](#) involves heterogeneous beliefs and overconfidence. These authors hypothesize that in times of financial distress, a larger share of investors become pessimists regarding the true creditworthiness of the sovereign, which contributes to increasing sovereign spreads further, more than that implied by risk-neutral pricing.

[Fostel and Geanakoplos \(2008\)](#) assume that emerging market bonds are an undeveloped asset class, where heterogeneity of rational investor priors about the future (optimism, pessimism) and market incompleteness matter most in the development of a time-varying risk premium in bonds. When bad news arrives, the share of pessimists rises, there is a flock to good collateral assets, which (due to market incompleteness) raises spreads on emerging market bonds together with those in corporate bonds. Further, this fall in demand affects lower rated issuances more, which explains why bonds with higher risk experience a larger rise in their spreads.

3.3 Comparison of proxies of credit risk

3.3.1 CDS spreads vs bond spreads

There have been two focal points of the sovereign credit risk literature regarding the relationship of CDS and bond pricing. One of these aimed to discern, which market acts as the primary source of price discovery and hence what is the direction of information flow between prices in the two markets. The general methodology used is Granger-causality testing. [Augustin \(2014\)](#) provides an overview of the related literature segment. Based on his account results have been mixed across studies and the country-time samples examined.

Second, several studies in the literature analyzed the sources of discrepancy between spreads in the two markets, the CDS-bond (or CDS-cash) basis. As seen in the previous section, both spreads should be well approximated by $h\lambda$, the expected default probability and the loss given default. However, empirically, CDS spreads and bond spreads of the same issuer were often significantly different.

[O'Kane \(2011\)](#) provides several explanations. Some of these are related to differences in the contractual terms of the two products, while others are related to differences in the two markets where the products are traded. The following factors act to relatively decrease CDS spreads and hence lower the basis: (i) protection sellers in the CDS contract have the benefit of being able to choose to deliver the cheapest bonds in a default and so bondholder losses could be higher than the CDS payout; (ii) protection sellers receive the accrued premium at default since the last payment, whereas bondholders may not receive accrued interest in a default; (iii) it is easier to take a long position on the issuer in the CDS market (sell protection) because of

lower trading costs (CDS are unfunded positions, whereas buying bonds requires funding)⁹; (iv) CDS contracts involve counterparty risk, which is a more substantial risk for the party buying protection.

Acting instead to relatively increase CDS spreads and thus the basis are the following factors: (i) standard credit events triggering CDS may be wider than defaults on a bond, which makes the protection seller position less attractive compared to holding the bond; (ii) it is easier to take on a short position in the CDS market (buy protection) than in the bond market, which creates additional demand for the protection buying side increasing the CDS spread.

Augustin (2014) summarizes results of empirical papers that investigate the relative importance of these factors. Again, the picture is mixed, funding costs of holding the bond, counterparty risks involved in CDS positions and relative liquidity of the markets all seem important.

3.3.2 Credit spreads vs ratings

Credit ratings and credit spreads often indicate different levels of credit risk, which originates from discussed properties and biases of these indicators with respect to default probabilities. Credit ratings are lagged indicators of credit risk and their ordinal scale is can only match ranges of default probabilities. Credit spreads on the other hand are influenced by expected recovery rates next to default probabilities and the significant and volatile time-varying risk premia overestimate true default probabilities.

There are several studies that investigate the proper functional form to use to match the ordinal rating scale with the continuous measure of credit spreads. Larraín, Reisen and Von Maltzan (1997); Rowland (2004); Kodres, Hartelius and Kashiwase (2008) all find that the logistic specification for transforming the rating scale increases the fit compared to a linear transformation especially at the riskier end of the spectrum. Close to the advice of these papers, most empirical studies that include ratings as explanatory variables in credit spread regressions, beginning with Cantor and Packer (1996), use a log-linear specification which has the logarithm of the credit spread explained by a linear transformation of ratings. Kocsis and Mosolygo (2006) allow a flexible functional form in cross section regressions that encompass both a linear and a log-linear specification and conclude that the exponential component for linear ratings (i.e the basis for a logarithmic spread specification) appears necessary to capture the curvature for riskier issuers (but not advanced countries) and that the exponential component seems more important in a cross section where risk premia is elevated within credit spreads.

The functional form between ratings and spreads is implicitly a result of functional forms of the ratings – default probabilities and credit spreads – default probabilities relationships, i.e

⁹Oehmke and Zawadowski (2015) provide a formal model based along these lines and show that CDS initiation has two opposing effects: it acts to reduce demand for bonds as the CDS market crowds investors out, but also lowers bond spreads as allocation improves. Oehmke and Zawadowski (2016) point out that net CDS notional outstanding is larger for entities with more negative CDS-bond bases suggesting that there is an arbitrage activity in the CDS market, which acts to compress the basis.

functional forms of these indicators with true sovereign credit risk. [Remolona, Scatigna and Wu \(2007\)](#) base their indicators on this idea: they use empirical default frequencies published by rating agencies for each rating notch to calculate the implied risk neutral credit spreads. They then use these risk neutral spreads to infer the size and evolution of risk premia on credit spreads. Similarly [Cunningham and Hayes \(2001\)](#) also derive ratings and spreads linked by default frequencies and observe that a proper functional form is then log-linear.

As mentioned at the beginning of the chapter, ratings have been found to be predicted by credit spreads by empirical studies. The reverse causal direction has also been extensively studied in the literature, namely whether rating announcements have an effect on credit spreads [Larraín, Reisen and Von Maltzan \(1997\)](#); [Gande and Parsley \(2005\)](#); [Fulop \(2006\)](#); [Binici and Hutchison \(2018\)](#). The general consensus emerging from these papers is that such an impact is asymmetric, with negative announcements (worsening credit outlook or downgrades) often found to have significant market impact whereas this is usually not true for positive announcements, although [Ismailescu and Kazemi \(2010\)](#) finds more consistent rating shocks on CDS for upgrades.

CHAPTER 4

Empirical literature

Having reviewed how fundamentals theoretically affect sovereign credit risk (Chapter 2) and how main indicators of sovereign credit risk measure this concept (Chapter 3), the current chapter turns to an analysis of the empirical results concerning fundamental determinant effects on sovereign credit risk indicators. The key take away from this analysis is that the empirical literature has failed to find robust, statistically significant effects even on those fundamentals, where theory had a clear prescriptions on the sign of the effect.

The following survey is based on 77 empirical papers published in the last three and a half decades, starting with the 1983 study of Sebastian Edwards ([Edwards, 1983](#)) and ending with papers in 2017. It is, of course, not a complete enumeration of studies in this field, but it includes the most frequently cited empirical papers and is the widest survey of the literature on fundamental determinants of sovereign risk to date that I am aware of.

Several disclaimers are in place here. This review is concerned specifically with the empirical literature analyzing impacts of fundamental determinants on sovereign risk as measured by ratings, (FX) bond spreads and CDS spreads. It also includes several papers, which have a different focus (contagion and spillover issues; sentiment and market liquidity; bond issue or credit default swap technicalities), but which (as a side) estimate fundamental effects. The survey does not, however, intend to cover the literature on these related topics. Also, studies, which do study the relationship between sovereign credit risk and fundamentals, but work with dependent variables outside of the scope of the thesis (e.g. domestic bond yields, asset swap spreads, foreign currency exchange rates, equity market indicators) are also excluded from the analysis even if one could plausibly argue that these indicators can also serve as proxies for sovereign risk.

Suggested reviews that extend to many of these related topics in general, without the constraint of also analyzing effects of domestic fundamental effects, are [Augustin \(2014\)](#), which surveys the literature on sovereign CDS spreads, and [Kraussl, Lehnert and Stefanova \(2016\)](#) that takes into account recent papers on the eurozone sovereign debt crisis. The theoretical literature is reviewed by [Panizza, Sturzenegger and Zettelmeyer \(2009\)](#), [Aguilar and Amador \(2014\)](#) and [Stähler \(2013\)](#), among others. A less recent, but overarching work containing a thorough literature survey is [Andritzky \(2006\)](#).

4.1 Trends in model choice

Empirical models of sovereign credit risk have naturally evolved in concordance with trends and events in economic history, economic thought, availability of data and interests of policymakers.

Economic history had many influences. International lending by private lenders to sovereign borrowers in developing countries was limited in much of the period after World War II and before the 1970s, so research on sovereign credit risk was scarce. Interest in sovereign credit risk increased in the 1970s when lending to developed countries, mostly in Latin America, expanded. This was partly a result of the oil price boom as windfall revenues of oil exporters, so-called petrodollars, landed in developed nation banks. The excess liquidity this created and the perceived improvement in emerging market investment prospects triggered a lending boom in these markets initially taking the form of syndicated bank loans and later entailing emerging market bond issuances. As credit expanded, soon a wave of sovereign defaults ensued (see [Andritzky, 2006](#), pp. 15-25, for a more detailed historical account of this period).

These events created academic interest in the subject and there were pressing policy issues regarding restructurings to be resolved. Data on sovereign default however was scarce and most academic papers were primarily theoretical in nature ([Eaton and Gersovitz, 1981](#); [Cooper and Sachs, 1984](#); [Krugman, 1985](#)). Empirical studies of this era were mostly binary choice models with dependent variables comprising dummy variables of credit events (see [Frank and Cline, 1971](#); [McFadden et al., 1985](#), and further references therein). The first models with (primary market) credit spreads as the dependent variable were pioneered by papers of Sebastian Edwards ([Edwards, 1983, 1986](#)). The econometric methods used at the time were multivariate regressions on cross-sections, pooled data or on unbalanced panels.

In the 1980s and 1990s international bond markets in emerging markets expanded further and their secondary markets became more liquid. Credit rating agencies began rating more and more emerging market sovereigns which was a consequence, but also a cause of expanding bond markets. Data on macroeconomic fundamentals also became more abundant, better standardized and disseminated and available at higher frequencies. The improvement in data availability contributed to balanced panel and time series econometric methods.

The Mexican tequila crisis of 1994 and the Asian crisis in 1997-1998 turned interest toward the issue of how much external factors contributed to financial stress in countries besides domestic fundamentals. In the Mexican crisis low US rates and global liquidity conditions were suspected to act as 'push factors' that contributed to excessive credit growth. The effect of US rates and high yield spreads was ambiguous, but global financial conditions were generally found to be significant ([Eichengreen and Mody, 1998](#); [Ferrucci, 2003](#); [Herrero and Ortiz, 2004](#); [Grandes, 2002](#); [González-Rozada and Yeyati, 2008](#)). The experience in the Asian events that the crisis spread across countries and regions brought explanations based on macroeconomic or common creditor links (spillovers), structural breaks in fundamental effects on spreads (theories of wake up call and fundamental contagion), and shifts in the unexplained component of sovereign spreads (shift contagion) as described in Chapter 2.

Focus of the empirical crisis literature shifted from sovereign bonds more towards foreign exchange rates and equity indices. On one hand, it was mainly the over-stretched, foreign currency indebted corporate sector and not government debt, which was at the epicenter of the Asian

crisis. On the other hand, as a consequence of smaller government indebtedness in the region, secondary bond markets were less liquid and thus bond price quote data was less available and less reliable making any empirical analysis on sovereign credit risk difficult. Currency rates and equity indices were better suited indicators to analyzing cross-country co-movements in this period.

However, there was an increasing empirical literature investigating bond spreads in the European Union, where the euro replaced several national currencies. The eurozone established a single interbank market and interbank (FRA/IRS) yield curve. Sovereign yield spread differences decreased substantially, but did not completely disappear. Yield spreads were small compared to emerging markets and yield differences to the core risk-free asset, German Bunds, were occasionally negative. As a result, empirical models studying this segment chose specifications in which the yield spread was linear instead of the previous emerging market literature that worked with logarithmic spreads since the pioneering work of [Edwards \(1983\)](#).

A characteristic topic of the European segment of the literature was its interest in the liquidity (bond market and bond issue-specific liquidity) component of spreads next to domestic fundamentals and market risk premia. Interest in this component has remained characteristic of the developed country sovereign credit risk literature ([Beber, Brandt and Kavajecz, 2008](#); [Favero, Pagano and Von Thadden, 2010](#)).

Interest in sovereign credit risk flared up during the financial crisis. On one hand, fiscal effects of financial sector bailouts in developed countries raised concerns about sustainability of a large public debt overhang. The financial (and sovereign) crisis triggered an expansion on the theoretical ([Acharya, Drechsler and Schnabl, 2014](#); [Gennaioli, Martin and Rossi, 2014](#)) and empirical links and feedback ([Mody, 2009](#); [Gerlach, Schulz and Wolff, 2010](#); [Ejsing and Lemke, 2011](#)) between sovereign credit risk and financial sector systemic risk.

On the other hand as voices about 'decoupling' (the idea that emerging markets were strong enough to withstand a crisis in the developing world) were muted after Icelandic events in October 2008, fears regarding emerging market sovereign defaults increased.

Compared to previous empirical research, better data availability in the EU allowed using monthly frequencies in studying the relationship of sovereign spreads and macroeconomic fundamentals. Moreover, studies could include more survey data and projections on macroeconomic data instead of the traditional (backward-looking) publications. The availability of indicators expanded both within each countries and the data standardization and dissemination drive of international institutions has also benefited cross-sectional studies.

These developments contributed to an increased variability in model setups in the current empirical literature. The heterogeneity/ambiguity was studied by several papers ([Maltritz and Molchanov, 2014](#)) [De Haan, Hessel and van den End \(2014\)](#), and the current chapter also contributes in this respect.

A segment of the literature turned towards higher frequency, time series estimation of spread determinants, employing daily or weekly series. Fundamentals in these studies were often prox-

ied by local equity indices or foreign currency rates (e.g. [Dieckmann and Plank, 2011](#); [Longstaff et al., 2011](#)). The run up in the literature using textual inputs in finance has permeated the empirical sovereign risk literature as well and may provide better high frequency proxies for fundamentals (see [Fülöp and Kocsis, 2018](#), for references). Although specifications vary, many of these studies used ARDL, VECM models and dynamic panels. Other studies, for instance those studying politics and institutions ([Eichler, 2014](#); [Eichler and Plaga, 2016](#); [Chen and Chen, 2018](#); [Jeanneret, 2018](#)) continue to use annual data on which these are available with the more traditional logarithmic spread dependent variable and fixed effects panel estimation.

Current popular topics in the sovereign risk literature include the sovereign-bank nexus ([Kraussl, Lehnert and Stefanova, 2016](#), provides several references); a new political economy drive that aims to explore how politics and institutions play a role (e.g. the above referenced papers); an ongoing examination of cross-country and cross-asset linkages (contagion, spillovers) ([Ehrmann and Fratzscher, 2017](#); [De Santis and Zimic, 2018](#)) and, relatedly, the changes in correlation structures across various regimes ([Kiss, 2017](#); [Piljak and Swinkels, 2015](#)).

Table 4.1 summarizes several aspects of the selected empirical studies.

Some of the trends mentioned above are apparent from the table (studies are listed by publication date). First, the initial focus on emerging markets and the shift towards European countries after the crisis is clearly visible. Second, regarding the dependent variable, before the financial crisis the logarithm of bond spreads were used. As of the crisis, CDS spreads have gained more ground. Bond yield spreads have still remained the basic choice, but in nominal not logarithmic functional form. This change is not restricted to eurozone studies of bond yield spreads, it is also prevalent in studies of emerging markets and studies of a global focus ([Eichler, 2014](#); [Maltritz and Molchanov, 2014](#); [Benczúr and Ilut, 2016](#), to cite some recent examples). Rating determinants were however mainly studied in earlier studies.¹ Third, there is a discernible trend towards more higher frequency data, though the quarterly-monthly range has remained most popular to date.

There are no obvious patterns regarding the dimensions of samples and variables. Except for banking system related variables, which were absent from models before the crisis, the presence of other explanatory variable groups has been more or less time-invariant.

¹There have been several exceptions ([Erdem and Varli, 2014](#); [Procasky and Ujah, 2016](#); [Gibson, Hall and Tavlasi, 2017](#)) and it is not to say that there is no current literature on credit ratings. The sovereign rating literature however is now less concerned with its domestic fundamental determinants (rating agencies now publish their methodologies anyway, see Chapter 3), this literature rather focuses on rating change impacts or consistency of ratings with credit spreads or ratings of other agencies.

Table 4.1: Chosen samples and variables in the empirical literature

STUDY	SAMPLE ^a						DEPENDENT ^b						EXPLANATORY ^c									
	ABBR	FREQ	T years	No. countries	EM	EZ	RAT	Log SPR	Log CDS	Log SPR	CDS	No. var's	REAL	EXT ERN	FIS CAL	BANK	POL INST	NOMI NAL	FOR EIGN	BOND SPEC	RAT ING	
Edwards (1983)	Edw83	1	5	19	x			x				7	x	x	x					x		
Edwards (1986)	Edw86	1	5	26	x			x				9	x	x	x			x		x		
Pryce (1990)	Pry90	1	12	54	x		x					9	x	x	x		x					
Cantor and Packer (1996)	CP96	1	1	35	x		x					8	x	x	x		x					
	CP96b	1	1	35	x			x				9	x	x	x		x				x	
Eichengreen and Mody (1998)	CP96c	1	1	35	x			x				8	x	x	x		x					
	EM98	1	6	37	x		x					8	x	x	x		x		x	x		
Min (1998)	EM98b	1	6	37	x			x				9	x	x	x		x		x	x		
	Min98	1	5	11	x		x					14	x	x				x				
Kamin and Von Kleist (1999)	KK99	1	6	30	x		x					4						x		x		
Ades et al. (2000)	Ade00	2	5	15	x		x					8	x	x	x		x		x	x		
Budina and Mantchev (2000)	BM00	2	5	1	x		x					4						x				
Benczur (2001)	Ben01	1	23	37	x							8	x	x	x		x		x			
Nogués and Grandes (2001)	NG01	2	5	1	x		x					5	x	x	x				x			
Westphalen (2001)	Wes01	2	7	26	x							5							x			
Grandes (2002)	Gra02	2	7	3				x				6	x	x	x							
Afonso (2003)	Afo03	1	1	70			x					6	x	x	x		x					
Ferrucci (2003)	Afo03b	1	1	70			x					6	x	x	x		x					
	Fer03	2	13	27				x				10							x			
Rojas and Jaque (2003)	RJ03	2	4	1								5	x	x					x			
Bernoth, Schuknecht and von Hagen (2004)	Ber04	1	12	13		x						16	x	x	x		x		x			
	Ber04b	1	12	13		x						10	x	x	x		x		x			
	Ber04c	1	12	13		x						10	x	x	x		x		x			
	BP04	3	8	52				x				9	x	x	x							
Borio and Packer (2004)	Row04	1	1	29	x			x				3	x	x								
Rowland (2004)	Row04b	1	1	29	x							2	x	x								
	Row04c	1	1	48	x		x					5	x	x								
Rowland and Torres (2004)	RT04	1	5	16	x			x				5	x	x	x							
Baek, Bandoopadhyaya and Du (2005)	Bae05	2	8	5	x							8	x	x	x							
Andritzky, Bannister and Tamirisa (2007)	And07	3	7	12	x			x				8	x	x	x				x			
Remolona, Scatigna and Wu (2007)	Rem07	1	5	27	x		x					7	x	x								
Baldacci, Gupta and Mati (2008)	Bal08	1	11	30	x			x				8										
Dall'Ami, Masson and Padou (2008)	Dal08	2	14	17	x			x				4			x							
González-Rozada and Yeyati (2008)	GY08	3	13	33	x			x				4			x							
Siklos et al. (2008)	Sik08	2	11	19	x			x				12	x	x					x		x	
	Sik08b	2	11	19	x							12	x	x								
Attinasi, Checherita-Westphal and Nickell (2009)	Att09	3	3	10		x						5			x							
Borensztein and Panizza (2009)	BP09	1	8	31	x							7	x	x		x					x	
Ebner (2009)	Ebn09	2	9	11	x							11	x	x	x							
Haugh, Ollivaud and Turner (2009)	Hau09	1	5	10								5			x				x			
Mody (2009)	Mod09	3	4	10		x						4										
Öztaay, Özmen and Şahinbeyoğlu (2009)	Oza09	3	10	18	x							2							x			
Schuknecht, von Hagen and Wolswijk (2009)	Sch09	2	19	15		x						7			x					x		

STUDY	SAMPLE ^a						DEPENDENT ^b						EXPLANATORY ^c												
	ABBR	FREQ	T years	No. countries	EM	EZ	RAT	Log		Log CDS	SPR	CDS	No. var's	REAL	EXT		FIS CAL	BANK	POL		NOMI NAL	FOR EIGN	BOND SPEC		RAT
								ING	SPR						ERN	INST			SPEC						
Paniagua, Sapena and Tamarit (2016)	Pan16	2	14	11		x					x		4	x		x				x					
Pagano and Sedunov (2016)	PS16	2	7	15							x		6	x		x	x			x		x			
Procasky and Ujah (2016)	PU16	1	10	109			x						7	x	x				x						
Gibson, Hall and Tavas (2017)	Gib17	2	17	5		x					x		5	x		x			x		x				x
	Gib17b	2	16	5		x	x						5	x		x	x	x		x					

Sources: Author's compilation.

Notes: Descriptives of 77 selected studies that present regressions of domestic fundamental determinants on credit ratings or (FX) bond spreads or CDS spreads.

^a FREQ: data frequencies (1: cross-section or annual; 2: quarterly or monthly; 3: weekly or daily). EM: only Emerging Markets in the sample. EZ: only Eurozone countries in the sample.

^b RAT: Long-term Credit Ratings; (Log) SPR: (logarithm of) hard currency bond spreads; (Log) CDS: 5y Credit Default Swap Spreads

^c Number of explanatory variables in selected regressions and binary variables of the regression containing a variable belonging to the following variable groups:

REAL: real economy and level of economic development related; EXTERN: external position flow variables, central bank reserves, relating to external debt; FISCAL: fiscal balance related; government debt related; POL INST: related to political system, stability; related to institutional strength (includes default history, EZ/EU membership); NOMINAL: inflation, nominal exchange rate, terms of trade; BANK: banking, financial sector related; FOREIGN: global risk proxies, contagion; BOND_SPEC: bond issue specific characteristics.

4.2 Reported effects of fundamentals

Theory provided guidelines about several fundamentals that should have an influence on sovereign credit risk variables. In empirical applications the choice of the specific proxies for fundamentals varied widely across individual studies. I grouped the exogenous variables of literature entries according to which fundamental concept they pertain to and categorized some other (external, non-fundamental) variable groups. I also selected and will refer to the more often included variables as key variables.

Figure 4.1 provides an overview on the key variables included in the selected studies of the empirical literature together with the signs and significance that were reported for these variables in regressions of sovereign credit risk variables.

Real GDP growth rate and GDP per capita were the two most often used proxies for real economic growth and level of development (41 and 18 times, respectively). Investment to GDP and survey expectations of real GDP growth were also popular. Other, less often used proxies were unemployment, industrial production, economic sentiment, investment growth and the economic risk indicator of ICRG. In total 65 of the total 95 empirical models had at least one proxy for this concept.²

As Figure 4.1 attests, the majority of studies which included the GDP growth rate and GDP per capita had estimated significant negative effects on sovereign credit risk. About 40 percent of studies with these variables, however, had coefficient estimates that were not significant.

Regarding the external position of the country, the three key proxies used in the empirical literature were the current account balance to GDP, the central bank reserves to GDP and the external debt to GDP (22, 20 and 16 times, respectively). Again many other proxies have been used, the most popular of which, were trade openness (exports plus imports to GDP), the trade balance, exports, export growth, exports to GDP, import growth in terms of flow variables and reserves to imports, external debt to exports, external debt service in terms of stock variables. 64 studies had some sort of proxies for the external position. External debt to GDP and reserves to GDP had a 55-70 percent rate of being significant with the correct sign. However, estimates of the effect of the current account were mixed. Half of the studies including this proxy found it to be insignificant and four-four studies found it to significantly increase or significantly decrease sovereign credit risk.

The fiscal position was proxied by some indicators in 70 out of the 95 models in my literature sample. The most often used proxies were the government debt to GDP rate and the fiscal balance (or deficit) to GDP ratio with measures of expected fiscal balance being third (35, 33 and 12, respectively). Some other proxies were the debt service to GDP, expected debt to GDP, quadratic forms of the fiscal balance and the debt ratio, tax to GDP and government expenditure to GDP rates. The most precise key variable was the expected fiscal balance, where three-

²In most of the 77 papers studied there was a benchmark specification that could be selected. In 15 cases, however, this was not straightforward and I chose to include 2 or 3 specifications. Table 4.1 identifies these studies.

Figure 4.1: Signs and significance of key variables in the empirical literature

Sources: author's calculations based on studies reported in Table 4.1.

Notes: The figure shows the number of studies where each explanatory variable had the: a) correct sign and was significant (intuitive sign), b) was significant but had the opposite sign as expected from theory (wrong sign), c) was insignificant, d) had mixed signs and/or significance across models.

Explanatory variable abbreviations: dGDP: real GDP growth rate; GDPcap: GDP per capita; CAGDP: current account to GDP; RESGDP: foreign currency reserves to GDP; EDEBTGDP: external debt to GDP; FBALGDP: fiscal balance to GDP; GDEBTGDP: government debt ratio; expFBAL: expected fiscal balance to GDP; dCPI: consumer price growth; defhist: history of previous default; REER: real effective exchange rate; VIX: VIX index (S&P500 implied volatility); BBBspr: corporate credit spreads (US: BBB to Treasury, EU: KfW to Bund); DEVmmr: developed country short rate (US: Fed, EU: ECB rate); DEVlong: developed country long-maturity interest rate; maturity: time to maturity or duration of bond.

fourths of estimates were significant with the correct sign. The debt ratio had the correct sign with significance 21 out of 36 cases, but was insignificant 11 times. Estimates of the simple fiscal balance were less precise, it was found insignificant more times than significant with the correct sign (14 and 12).

Proxies for political stability and institutional strength varied widely across studies. I included default history here, which was available in 15 models. Default history was estimated to significantly increase sovereign risk in 11 of these with the remainder finding insignificance. Other proxies in this area were the ICRG political risk indicator, IFO WES and World Governance political stability indices, various corruption indicators, governance indicators, Heritage Foundation indices, dummy variables for belonging to the developed group and dummies of EU and EMU membership. However, neither were employed in more than 5 cases. On the whole,

38 models included some proxies for this category of fundamentals.

Even less, only twelve, studies accounted for the health of the domestic financial sector. This number is in part the result of my selection principles. Many studies are left out that do not explicitly target domestic fundamentals and restrict their investigation to spillovers, contagion across sovereign and bank credit markets. However, the low number may also be due to scarce available proxies and less interest in these variables before the crisis. As mentioned in the previous section, the importance of the financial sector for sovereign risk became really apparent during the financial and eurozone sovereign crises. Those few studies that proxied bank sector health used various indicators from bank credit ratings, to bank asset value and growth, bank equities and credit risk variables.

Many other proxies were used in the empirical literature that I would categorize as domestic nominal and financial variables. The most often used of these were the consumer price inflation rate and the real effective exchange rate (28 and 11 times, respectively). Various other versions of inflation (expectations, real inflation, inflation gap), the nominal exchange rate, terms of trade measures, local equity price index and its volatility, local interest rates were also used representing this category. Overall, more than half of the studies included at least one related proxy. CPI inflation was found significant and positively related to sovereign credit risk in 16 of the 28 cases with 7 findings of no significance. The real exchange rate was more mixed, was significant with the correct sign only 5 out of 11 times.

Credit ratings were included as explanatory variables in 13 studies of sovereign credit spreads and were found significant and correctly signed in all but one of these cases. Ratings either entered directly in the regression or were included as a proxy for the additional information in ratings not already included in other fundamental proxies. In these latter cases residuals were used from a first stage regression of credit ratings on fundamentals ([Eichengreen and Mody, 1998](#); [Kocsis and Monostori, 2016](#)).

Multiple regression (least-squares) estimates of variable (partial) effects are covariances of each exogenous variable with the dependent conditioned on all other variables (Frisch-Vaugh-Lovell Theorem). Hence rating coefficients are the same in the two cases, because residuals of the first stage are exactly the result of such conditioning. However estimates of fundamentals will be different since fundamental effects will not be conditioned on ratings. Ratings are themselves strongly affected by fundamentals, and so conditioning on ratings removes much of fundamental variables covariance with sovereign spreads, increasing uncertainty of estimates and lowering explained variance share. The second method conceptually attributes all the variation in the dependent that is explained by ratings and fundamentals jointly to fundamentals. This is therefore a more efficient estimation method if the direction of causation can be assumed to run from fundamentals to ratings. If credit ratings are assumed to affect sovereign spreads as argued by several studies ([Gande and Parsley, 2005](#); [Binici and Hutchison, 2018](#), and others, see Chapter 3), then instrumenting by rating lags may be the best option.

Foreign influences were captured by a wide array of indicators and the majority of studies

(64) included some kind of such proxies. The most popular indicators were the VIX index, developed country credit spreads over sovereign benchmark rates and developed country interest rates both short- and long-maturities. The VIX index and corporate credit spreads were usually found significant with the correct sign. Interestingly, developed country interest rates were more often found to have the sign opposing the theoretical (positive) relationship with sovereign credit risk. Of all key variables, developed country rates had the lowest ratios of intuitive signs.

Finally, proxies relating to bond-specific attributes were included in nearly a third of the studies, maturity of bonds being the most popular of these. Other proxies included bond issue size and bid-ask spreads.

4.3 What accounts for cross-study differences?

Seeing the diversity of results regarding the signs and significance of most fundamental proxies, it is natural to ask, how much of this variation can be explained by the different approaches and sampling characteristics that various studies in the literature have opted for.

Most importantly for the goals of the thesis, I am interested in whether sample selection had an effect as it could call attention to heterogeneity of effects across time and cross-sections. Of course this can only be an indication of such heterogeneity. Not finding such sample selection effects does not preclude heterogeneity of effects, because here we are looking at significances and signs but it could well be that effects change orders of magnitude without switching sign or changing significance. Finding such sample selection effects also does not prove heterogeneity either. Better data availability over time could also have allowed inclusion of better proxies of fundamentals, which could also have helped finding true relationships. If more variables were included with essentially the same content, it could also lower significance of individual effects due to collinearity and there could have been trends in modelling choice, which would then suggest sample effects to vary over time.

Other than the effect of sample choice, I also look at whether model specifications resulted in different results.

Bivariate correlation of sample/model characteristics and estimate consistency with theory

To investigate the issue, I first look at simple linear bivariate correlations between the ratio of correct signs (the variable significant with the theoretically plausible sign) and model/sample specification characteristics.

These statistics are reported in Table 4.2, with fundamentals in rows and model/sample attributes in columns. Positive correlations suggest that the studies with the given model/sample specification have improved the ratio of correct signs.

The first four columns of the table deal with the choice of the dependent variable. Having credit ratings as the dependent (as opposed to sovereign FX bond spreads or sovereign CDS spreads) had positive correlation coefficients in case of most fundamentals, indicating that esti-

mated fundamental effects more closely aligned with theory for rating regressions than for spread regressions. Ratings appear to have relatively increased the significance rate of especially those variable that pertain to the real economy and nominal variables.

Spreads being in logs instead of nominal (basispoint values) (second column) seems to have also contributed to higher significance rates for most variables with the notable exception of real growth and GDP per capita, in which cases taking logs seems to have taken estimates further from those expected by theory.

Regarding the functional form of having the dependent in levels (typically fixed effects models) or first differences (these two dummies distinguish from quasi-differenced forms) suggest that first-differenced forms of the dependent lead to findings of insignificance almost uniformly across variables.

To sum up, the fundamental effects were closest to theoretical predictions for models with ratings as the dependent variable, then logarithmic spreads and least so for models of linear spreads. Differencing the dependent appears to have resulted in less empirical support for theoretical predictions.

Of course, some of these correlations could just be a result of other sample specification features being correlated with these modelling choices of the dependent. Having credit ratings was characteristic of studies using annual frequencies or cross-section samples, where the time dimension was short while the cross-section was wide. If heterogeneity was important in time but not across cross-sections, this could have increased correlation with ratings. This selection effect seems to be relevant in the case of the GDP capita and the inflation rate, but not for GDP growth.

Logarithmic spreads were characteristic of pre-crisis studies on emerging markets. The time sample correlation with these variables (pre_2007 and post_2007 columns) are at times correlated with key variable signs, but the connection does not seem to be consistent across variables. There is more tentative evidence for the emerging market sample contributing to the correlation of logarithmic form and key variable signs.

The sample selection characteristic of having only emerging market countries in the sample increased correlation with developed country long interest rates suggesting that the high ratio of insignificance may partly be due to heterogeneity of this variable across regions. Reserves to GDP had more significant results on emerging market samples. In contrast, fiscal variables and the current account balance appear to have been more in line with theory in the eurozone sample.

Having larger country cross-sections or longer time series does not appear to have consistently increased or decreased significance of variable effects. More countries in the sample lowered significance of reserves and fiscal balance indicators, perhaps indicative of cross-country heterogeneity. Longer time series also had mixed effects contributing to more significant effect of maturity, but lowering significance of GDP capita, inflation and the real exchange rate, the latter perhaps the effect of having ratings as the dependent as mentioned above.

Table 4.2: Correlations: empirical specification features vs. ratio of theory-consistent sign

	MODEL AND SAMPLE SPECIFICATION										
	DEPENDENT				SAMPLE						
	RATING	log(SPREADS)	levels	first_diff	EZ	EM	N_country	T_years	has_pre2007	has_post2007	EXPLAN N_VARS
key variables (correct sign ratio)											
rating		0.312	0.312	-0.433	0.192	0.365	0.175	-0.207	-0.228	-0.312	-0.291
dGDP	0.312	-0.253	-0.246	0.010	0.029	-0.162	0.172	-0.095	0.006	-0.010	-0.300
GDPcap	0.707	-0.316	-0.707			-0.175	0.305	-0.434	-0.158	-0.189	-0.578
CAGDP	-0.149	0.379	0.153	0.026	0.261	0.111	0.050	0.185	0.103	0.194	0.511
RESGDP	0.099	0.328	0.179	-0.302		0.638	-0.284	-0.135	0.183	-0.302	-0.291
EDEBTGDP	0.174	0.135	0.221	-0.713		0.153	-0.129	-0.182		0.135	0.064
FBALGDP	-0.088	0.103	0.223	-0.281	0.307	0.069	-0.314	0.150	0.084	0.229	-0.164
GDEBTGDP	0.059	0.289	0.036	-0.219	0.139	-0.051	0.075	-0.073	0.052	-0.037	-0.407
expFBAL		0.174	0.408	-0.488	0.408	0.174	-0.385	0.023	-0.333	-0.174	-0.245
dCPI	0.404	0.068	-0.207	-0.177	-0.059	0.091	0.119	-0.313	-0.068	0.000	-0.355
defhist	0.107	0.107	-0.107			-0.302	0.288	-0.363	-0.107	-0.207	-0.328
REER	0.346	0.449	-0.069	-0.149	0.069	0.100	-0.365	-0.083		-0.267	0.027
VIX		0.199	0.036	-0.371	0.138	0.293	-0.230	-0.066	0.184	-0.370	-0.189
BBBspr		-0.043	0.372	-0.389	0.155	0.038	-0.103	0.106	-0.038	0.224	-0.231
DEVmmr		0.295	-0.013	-0.183	-0.142	-0.099	0.197	-0.094	0.066	-0.322	0.035
DEVlong		0.262	0.262	-0.364	-0.237	0.492	0.006	0.149		-0.185	-0.500
maturity		-0.167	0.327	-0.327	0.167	-0.167	0.386	0.604	0.480	-0.167	0.000
variable groups (correct sign & significance ratio)											
REAL	0.266	-0.130	-0.011	-0.293	-0.100	-0.016	0.199	-0.102	0.046	-0.005	-0.200
CA_TRADE	0.011	0.450	0.172	-0.336	-0.131	0.255	-0.137	0.097	0.089	-0.149	0.195
RES	0.059	0.194	0.089	-0.218		0.719	-0.210	0.120	0.274	-0.338	-0.095
EDEBT	0.172	-0.075	0.075	-0.431		0.065	0.036	-0.109	0.005	0.067	-0.097
FBAL	-0.197	-0.022	0.183	-0.071	0.316	-0.082	-0.351	0.139	0.138	0.393	-0.138
GDEBT	0.010	0.193	0.132	-0.154	0.251	-0.010	0.045	-0.034	0.073	0.029	-0.226
BANK	0.203	0.156	-0.185	-0.110	-0.054	-0.024	-0.066	-0.335	-0.339	-0.297	-0.164
POL	-0.285	0.377	-0.133	0.200	0.200	-0.377	0.012	0.117	-0.200	0.285	-0.552
INST	0.134	0.267	-0.131	0.012	-0.349	0.079	0.216	-0.321	-0.149	-0.057	-0.317
NOMINAL	0.305	-0.132	-0.128	-0.182	0.030	-0.044	0.016	-0.212	-0.032	0.060	-0.340
LOCAL_FIN	0.197	0.016	-0.214	-0.099	-0.005	-0.049	-0.159	-0.280	-0.266	-0.098	-0.512
DEVEL_FIN		0.007	0.107	-0.273	0.097	0.024	-0.119	0.044	0.064	-0.156	-0.219
GLOBAL_FIN		-0.210	0.041	-0.397	-0.068	0.041	-0.113	0.095	-0.041	-0.041	-0.553
CONTAGION		0.667	0.408	-0.612	0.408	0.167	-0.254	-0.281	0.167	-0.408	-0.633
BOND_SPEC		-0.302	0.249	-0.249	0.302	-0.123	-0.136	0.007	-0.004	0.012	-0.121

Sources: author's calculations based on studies reported in Table 4.1.

Notes: The table shows bivariate Pearson's correlations between (rows:) explanatory variable (and variable group) correct sign ratios (the ratio of studies where the explanatory variables was reported to have significance and correct signs) and (columns:) sample/model characteristics (columns). Having a positive value suggests that the sample/model characteristic contributed to estimates more inline with theory.

Key explanatory variable abbreviations: see Figure 4.1.

Explanatory variable group abbreviations: REAL: real economy and level of economic development related; CA_TRADE: external position flow variables; RES: central bank reserves related; EDEBT: relating to external debt; FBAL: fiscal balance related; GDEBT: government debt related; POL: related to political system, stability; INST: related to institutional strength (includes default history, EZ/EU membership); NOMINAL: inflation, nominal exchange rate, terms of trade; LOCAL_FIN: local stock market index and foreign currency rates; DEVEL_FIN: financial indicators of developed countries; GLOBAL_FIN: global financial indicators (e.g. MSCI, EMBI global); CONTAGION: various indicators constructed to assess contagion from crisis countries; BOND_SPEC: bond issue specific characteristics.

The inclusion of data from pre-2007 samples or post-2007 samples did not have consistent impact across variables. Post-2007 samples seem to have contributed to less significant findings of fundamentals in case of credit ratings (as explanatory variables in spread regressions), reserves, real exchange rates and, perhaps counter-intuitively, the VIX index and developed country short rates.

The number of explanatory variables included decreased significance of explanatory variables across the board (suggesting problems with collinearity) with the notable exception of the current account balance.

Taking a look at Table 4.2 from the angle of variables, it is difficult to explain mixed effects of the more puzzling explanatory variables with features of the model or sample.

The current account balance had effects more inline with theory in models where the dependent was the logarithmic spread, when the sample was restricted to the eurozone and when

there were more explanatory variables included in the model. The fiscal balance estimate was less theory-consistent in models with dependent variable in first differences and in samples with larger cross-sections and outside of the eurozone, but these have similarly lowered the significant of expected fiscal balance, where the effect was more in line with theory. Similarly, model and sample specification features do not appear to provide much different effects in case of developed country interest rates compared to other variables. Based on this it seems more likely that these variables truly had less contribution to sovereign credit risk or they were worse proxies for their relevant fundamentals.

Multivariate analysis

Bivariate Pearson's correlations cannot account for partial effects of various model and sample characteristics simultaneously. Therefore I estimated logistic regressions where the dependent binary variables represented whether the key variables of the given literature entry was (value of 1) significant with the correct sign or (value of 0) it was of the other sign or insignificant. Explanatory variables in the logistic regression were the model and sample specification characteristics. Since the number of observations was not enough for testing individually the variables, I stacked fundamentals (key variables) in the regressions. These regressions therefore seek to explain, which model and sample features resulted in estimated effects of explanatory variables that were closer to theoretically implied signs.

Literature entries typically include a subset of the key variables in their specification and the selection cannot be assumed to be independent of model and sample features (the explanatory variables in the regression). Some variables are for instance not available on higher frequencies and may not be available on certain time or region samples.

This poses a sample selection problem, therefore I estimate Heckman model ([Heckman, 1979](#)), which aims to overcome this issue.

More formally the selection and response equations to be estimated are:

$$\begin{aligned} Z_{ji} &= W_{ji}\gamma + u_{ji} \\ Y_{ji} &= X_{ji}\beta + \epsilon_{ji}, \end{aligned} \tag{4.1}$$

where indices j and i refer to key variables and literature entries, respectively, Z and Y are the selection (whether the study includes the key variable) and response variables (whether the variable was significant with the correct sign) and W , X represent the model and specification features pertaining to the given study and dummy variables relating to key variables. Disturbances are assumed to be normally distributed with mean 0 and correlation ρ . The variance of the selection equation is normalized to one to identify the model. I estimated the model by maximum likelihood.

Table [4.3](#) reports estimation results.

Estimation results support some of the findings regarding bivariate correlations. Empirical

Table 4.3: Theoretical signs of variables versus model setups

	(A)		(B)		(C)	
	coeff	s.e.	coeff	s.e.	coeff	s.e.
specification characteristics						
publ_date	0.130*	(0.077)	0.154*	(0.081)	0.165*	(0.092)
RATING	0.115	(0.100)	0.085	(0.110)	0.309	(0.318)
CDS	-0.089	(0.061)	-0.056	(0.065)	-0.106	(0.096)
log(SPREAD)	0.122*	(0.066)	0.100	(0.072)	0.114	(0.100)
levels	-0.106	(0.119)	-0.115	(0.136)	-0.001	(0.428)
first_diff	-0.271***	(0.097)	-0.271**	(0.108)	-0.229	(0.268)
EZ	0.268**	(0.109)	0.344***	(0.125)	0.021	(0.420)
EM	0.140*	(0.074)	0.183**	(0.078)	0.118	(0.097)
N_country	0.022	(0.084)	0.069	(0.092)	0.004	(0.222)
T_years	-0.112	(0.079)	-0.130	(0.087)	0.029	(0.205)
freq_low	0.084	(0.087)	0.023	(0.095)	-0.053	(0.246)
freq_high	0.058	(0.071)	0.075	(0.076)	-0.071	(0.131)
has_pre2007	0.086	(0.069)	0.059	(0.074)	-0.059	(0.080)
has_post2007	0.006	(0.079)	0.017	(0.085)	-0.025	(0.107)
N_VARS	-0.121**	(0.047)	-0.133***	(0.051)	-0.126*	(0.071)
key variable dummies						
rating	0.612*	(0.329)			0.095	(0.064)
dGDP	-0.120	(0.267)			-0.113*	(0.068)
GDPcap	-0.002	(0.316)			-0.249**	(0.102)
CAGDP	-0.756**	(0.294)			-0.213***	(0.055)
RESGDP	0.008	(0.300)			-0.028	(0.070)
EDEBTGDP	0.149	(0.320)			0.092	(0.065)
FBALGDP	-0.481*	(0.271)			-0.026	(0.066)
GDEBTGDP	-0.018	(0.268)			0.062	(0.066)
expFBAL	0.401	(0.334)			0.148*	(0.082)
dCPI	-0.016	(0.283)			0.106	(0.079)
defhist	0.221	(0.321)			-0.030	(0.080)
REER	-0.401	(0.343)			0.059	(0.061)
VIX	0.278	(0.300)			-0.043	(0.068)
BBBspr	0.306	(0.287)			0.055	(0.075)
DEVmmr	-1.016***	(0.293)			-0.076	(0.060)
DEVlong	-0.636**	(0.317)			-0.005	(0.064)
maturity	0.000***	(0.000)			0.026	(0.075)

Sources: author's calculations based on studies reported in Table 4.1.

Notes: Response equation estimates are reported. These provide estimates of the extent to which model specification characteristics have increased/decreased the probability of having coefficients in line with theory.

Heckman sample selection models are estimated by maximum likelihood, where the selection variable specifies whether the key variable was included in the study (see text for details).

Specification (A) regresses the dependent on specification characteristics (see column headings in Table 4.2) and dummy variables representing each key variable block to control for heterogeneity in this regard. Specification (B) regresses the dependent on specification characteristics only. Specification (C) regresses the dependent on specification characteristics and dummy variables that distinguish between having the key variable in the model (of the literature entry) or not.

Key explanatory variable abbreviations: see Figure 4.1.

estimates of fundamental effects were closer to theoretical predictions, when

- the dependent was not in first differenced form;
- there were fewer explanatory variables included in the model;
- in more recently published papers (perhaps pointing to data quality improvement);
- when the study either contained only emerging market or only eurozone countries (suggesting that effects were different which may have lowered significance levels).

Other specification variables however do not seem to be significant, such as the frequency of observations, the time sample of estimation or the time length and cross-section width of the sample.

As observed before, ratings in models generally had higher significance levels, whereas the current account balance, the fiscal balance and developed country rates were significant less often than other variables. Specification C suggests that having real growth, development level variables and the current account in the model generally took estimates further from theory. Overall levels of significance improved, when the expected fiscal balance was included.

4.4 Time-varying effects of fundamentals on sovereign risk

The final section in the chapter turns to the segment of the empirical literature that assesses the subject matter of the thesis: time-variation in the sovereign risk – fundamentals relationship.

This segment of the literature is relatively new (about a decade old) compared to the overall sovereign credit risk empirical literature. A large part of its papers deal with structural breaks during the course of the global financial and the eurozone sovereign crisis, although some of the studies also assess experiences of changing relationships before and after the EMU creation in 1999 and some of the more recent papers also publish conclusions about experiences following the sovereign crisis.

4.4.1 Findings of the empirical literature

A uniform conclusion of studies dealing with structural breaks is that such differences exist across subsamples, but the exact findings regarding the nature of such time-variances are mixed. Several studies working on the eurozone sample conclude that fundamental effects have increased in the financial and/or the sovereign crisis, but the selection of variables representing fundamentals are varied. For instance, [Arghyrou and Kontonikas \(2012\)](#) looks at real exchange rate alignment, [Schuknecht, von Hagen and Wolswijk \(2009\)](#) finds fiscal balance and debt to have increased effects, in [Afonso et al. \(2018\)](#) projected debt and economic sentiment become significant in the crisis. [Beirne and Fratzscher \(2013\)](#) and [D'Agostino and Ehrmann \(2014\)](#) find an increased role for all variables of larger fundamental variable sets: debt, current account, fiscal balance and real growth in the former and projected real growth, debt, current account, unemployment, inflation in the latter. Also in [Giordano, Pericoli and Tommasino \(2013\)](#) public debt, private debt, GDP growth and the current account all have increased effects in the crisis. In several studies proxies of banking sector vulnerability are confirmed to be more important in the crisis than before ([Zoli and Sgherri, 2009](#); [Mody, 2009](#); [Kallestrup, Lando and Murgoci, 2016](#), and [Bruha and Kocenda \(2018\)](#) in case of ratings).

However, other studies provide mixed or even contrasting evidence about crisis fundamental effects on spreads. [Bernoth and Erdogan \(2012\)](#) supports an increased effect for the debt ratio, but the deficit is insignificant (and of the wrong sign). [De Grauwe and Ji \(2013\)](#) report that debt,

current account and real exchange rate effects increased for EMU countries in the crisis, though several effects increase only for eurozone periphery countries and not for other countries in the sample. The real GDP growth is significant in the periphery, but both within and outside the crisis sample. Regression output in [Aizenman, Hutchison and Jinjark \(2013, Table 3\)](#) reveals some variables to have an increased effect (inflation, trade openness, external debt) in the crisis, but fiscal space loses significance. In [Galaritis, Makrichoriti and Spyrou \(2016\)](#) economic sentiment is only significant in the first part of the crisis and then switches sign.

On emerging market samples, results are heterogenous as well. [Andritzky, Bannister and Tamirisa \(2007\)](#) report increased effects of inflation and fiscal balance, but ratings and real GDP growth lose significance in the crisis subsample. [Comelli \(2012\)](#) splits the 2003-2011 sample in 2007 and finds that economic risk ratings (and US short rates) matter only in the pre-crisis sample. Political risks and financial risks are stable and do not appear to materially change in the crisis. [Csontó \(2014\)](#) has its samples split endogenously into volatility regimes. His reported results reveal that fundamental effects are mixed across these regimes: while the current account balance has a significant effect in the high volatility regime, external debt and reserves are significant in the lower volatility regimes. US rates are again mixed in their effects, whereas public debt and GDP growth seem to have largely stable effects across regimes. [Reusens and Croux \(2017\)](#), assesses effects on a global sample of credit ratings and reports some fundamental effects to increase in crisis (fiscal balance, economic development, external debt, GDP growth interaction with debt), but structural breaks are rejected for public debt, current account balance, inflation and default history.

A unanimous conclusion for both eurozone and emerging market spreads is the increased effects of global risk and risk premium variables, such as the VIX index and the high yield (BBB-AAA) corporate spreads. Another result that appears uncontested, but is not in the scope of the current analysis is that cross-country correlations have increased in the crisis sample (or in high volatility samples, e.g. [DeSantis, 2014](#); [Leschinski and Bertram, 2017](#), and many others). In fact, this result extends to various other asset classes ([Kiss, 2017](#); [Bekaert, Ehrmann, Fratzscher and Mehl, 2014](#); [Dungey and Renault, 2018](#)).

Since the sovereign crisis abated, most fundamental effects appear to have weakened again as found by some more recent studies ([D'Agostino and Ehrmann, 2014](#); [Boysen-Hogrefe, 2017](#)). [Kocsis and Monostori \(2016\)](#) and [Audzeyeva and Fuertes \(2018\)](#) also report such weakening effects in case of various fundamentals, but these studies also find that this result does not extend to political-institutional variables, whose importance have increased.

4.4.2 Possible reasons for such findings

The most popular theoretical underpinning for the observed changes in fundamental effects are based on the wake-up call hypothesis, which is attributed to [Goldstein \(1998\)](#) and popularized by [Moser \(2003\)](#), [Beirne and Fratzscher \(2013\)](#), and [Giordano, Pericoli and Tommasino \(2013\)](#)

in the sovereign risk arena. [Goldstein \(1998\)](#) refers to the wake-up call hypothesis in relation to contagion seen in the Asian crisis. Thailand was the first to experience financial market turbulence and investors appeared to 'wake up' in starting to price fundamentals in other countries, too, that were considered as important in leading to the crisis in Thailand (weak financial sectors with poor supervision, large external deficits, real exchange rate appreciation, declining investment quality, export slowdowns). This interpretation of contagion therefore posits that the subsequent financial turbulence in other Asian markets was a consequence of the characteristics shared across Asian countries. This hypothesis rests on the assumption of imperfect information about which fundamentals are important in pricing risks (whether because information is unavailable, costly to access or there are behavioral biases). Supporting this hypothesis, [Goldstein and Hawkins \(1998\)](#) show that those countries experienced larger turmoil, where problematic fundamentals were more adverse.

References in the literature to the wake-up call hypothesis either assume investors to have behavioral biases (which prevent them from properly assessing the role of fundamentals before the crisis) or investors are assumed rational, but then there are impediments to information flow. [Ahnert and Bertsch \(2015\)](#) proposes a theoretical model in the latter vein: in this model a crisis in the ground zero country reveals information about fundamentals in the crisis country and, based on known correlations with other countries, this may increase crisis probability elsewhere. In this model, though, crisis acts as a source of information revelation about fundamentals and not how (various) fundamentals affect crisis probabilities.

Another theory builds on multiple equilibria and self-fulfilling crises, where investors may or may not be rational. When multiple equilibria may exist regarding how spreads are determined, investors may suddenly shift from a good to a bad equilibrium, which may feature different spread – fundamental relationships. One reason for a reassessment in the eurozone sovereign crisis, as argued by [\(De Grauwe and Ji, 2013\)](#), could have been that the ECB capacity to act as a lender-of-last-resort was questioned. Switching between good and bad equilibria can be due to fundamental links (e.g. trade), liquidity shocks or even chance (e.g. rumors) as discussed in Chapter 2.

A more mundane, econometric reason for observing changing spread vs fundamentals relationships is model misspecification.

An insight of [Dailami, Masson and Padou \(2008\)](#) is that the relationship between sovereign spreads and US interest rates is non-linear, which causes US rates to have larger effects, when fundamentals are stretched (e.g. debt levels are high) than at times when repayment is easy. This explanation can be extended to other fundamentals as well. As Table 4.1 and 4.4 reveal, a significant share of the empirical sovereign literature (including most studies on the eurozone crisis) does not follow the [Edwards \(1983\)](#) tradition of modelling spreads and fundamentals in the log-linear relationship, but rather assume a linear specification. If the true specification is log-linear, then this is a simple explanation for finding higher coefficients for all explanatory variables, when the credit spread increases (i.e. during the crisis). A similar argument is made

by [Delatte \(2014\)](#), who promotes a more flexible non-linear model specification.

Table 4.4 suggests that structural breaks were found to be significant also in the minority of empirical studies that continued to use the log-linear specification. However, the results concerning which fundamental effects have changed are mixed in these studies.

Other econometric problems may be including proxies for fundamentals, which are noisy and/or biased. For instance, usual macroeconomic variables are backward-looking, whereas sovereign credit spreads assess future probabilities of default. Even if there are survey data available for some variables, those assess more benign baseline scenarios rather than the mean of the expectational distribution that asset prices should theoretically target. Also, there are several aspects of fundamentals, which simply do not have proper, timely observable proxies (political events, expectations of economic policy announcements, etc). These ideas are elaborated in detail in [Kocsis and Monostori \(2016\)](#) and [Fülöp and Kocsis \(2018\)](#). [Kocsis and Monostori \(2016\)](#) aims to overcome some of these difficulties by forecasting fundamental factors ahead using a large set of fundamental variables, whereas [Fülöp and Kocsis \(2018\)](#) uses information within textual data of the Reuters news archives.

As seen before in the overall empirical sovereign literature, the segment concerned with time-variation in effects is also divided in terms of its methods, variables and samples used. Some of these aspects are reviewed in Table 4.4. As the table shows, studies were roughly equally split between eurozone and emerging market samples. The dependent variable used varied across studies with a significant divide relating to the choice of working with levels of spreads or their (quasi-)differenced form.

The methodology regarding the assessment of time variation in effects can be (roughly) split into 4 different types. Split samples have been used most often, which estimate regressions on subsamples and then compare the significance and signs of effects across these regressions. Some more popular papers using this method are [González-Rozada and Yeyati \(2008\)](#), who split their 1993-2005 full sample in 2000, or [Arghyrou and Kontonikas \(2012\)](#), [Aizenman, Hutchison and Jinjarak \(2013\)](#), [De Grauwe and Ji \(2013\)](#) who split their samples into a pre-crisis and crisis sample. A similar method (e.g [Bernoth and Erdogan, 2012](#); [Beirne and Fratzscher, 2013](#); [Giordano, Pericoli and Tommasino, 2013](#)) uses crisis dummies to account for changes in explanatory variable effects, which is a more explicit estimation of the differences across time samples. Most of the studies assessing the wake-up call hypothesis for changes in fundamental effects follow this methodology. Only a handful of studies have used rolling regressions ([Comelli, 2012](#); [Afonso et al., 2015](#); [Kocsis and Monostori, 2016](#)), regime-switching models ([Georgoutsos and Migiakis, 2013](#); [Csontó, 2014](#)), and a smaller but increasing group of studies employed time-varying parameter models ([D'Agostino and Ehrmann, 2014](#); [Boysen-Hogrefe, 2017](#); [Gibson, Hall and Tavlás, 2017](#); [Afonso et al., 2018](#)).

Altogether, these differences across studies result in the disparate findings regarding the exact nature of time-variation in the effects of sovereign risk and fundamentals.

Table 4.4: Assessment of time-variation in the empirical sovereign risk literature

Author	tvar method	dep.form	sample	findings regarding time-varying effects
Kamin and Von Kleist (1999)	split	lnS	EM	higher rating effect in Mexico crisis
Andritzky, Bannister and Tamirisa (2007)	split	dlnS	EM	in crisis cpi, fbai becomes sign., but rat, dgdp lose sign.
González-Rozada and Yeyati (2008)	split	(d)lnS	EM	after 2000's: HY, rating effects weaker, US rates becomes neg.
Dailami, Masson and Padou (2008)	split	(d)lnS	EM	non-linearity of effects: larger when PD larger
Mody (2009)	cr.d, split	dS	EZ	after Lehman bank equity effects increase; debt becomes sign.
Schuknecht, von Hagen and Wolswijk (2009)	cr.d	S	EZ	after 2008 fiscal var (fbai, debt) and HY spread effect rise
Zoli and Sgherri (2009)	cr.d	dS	EZ	fund's effect up (debt and banks) and liq. becomes more important in crisis
Arghyrou and Kontonikas (2012)	cr.d, split	dS	EZ	REER, contagion become sign in crisis
Bernoth and Erdogan (2012)	tv.par	S	EZ	early 2000s debt, HY effect declined, both increased in crisis; fbai, BA spread insign.
Bernoth, Von Hagen and Schuknecht (2012)	cr.d	S	EZ	large increase in debt effect in crisis; liquidity sign. only before EMU
Comelli (2012)	split,roll.r	lnS	EM	VIX effect increases; econ risk, US 3m insign. in fin.crisis; fin.risk and pol risk stable
Fender, Hayo and Neuenkirch (2012)	split	dS	EM	fund's weaker eff.in crisis (fbai,rating), effects of fin.var's, cx-correls larger
Oliveira, Curto and Nunes (2012)	split	dS	EZ	fund effects (growth, cpi, debt, CA) and int'l risk premium increases in crisis
Aizenman, Hutchison and Jinjarak (2013)	split	dlnS	glob	fund effects changes mixed, TED spread effect increases in crisis
Beirne and Fratzscher (2013)	cr.d	S	glob	fund effects increased especially in EZ
Bobetko, Dumičić and Funda (2013)	split	dS	EM	fiscal, growth effect increase in 2008
Georgoutsos and Migiakis (2013)	reg.ch	dS	EZ	econ sent and fin.var's effect larger in high vol regimes
Giordano, Pericoli and Tommasino (2013)	cr.d	dS	EZ	after 2009 debt, dgdp, CA, VIX effects increase
De Grauwe and Ji (2013)	split	S	glob	CA, REER and debt matters for EZ countries in crisis; drgdp stable
Csontó (2014)	reg.ch	S	EM	fund's, US rates mixed effects; VIX, CA sign. in highvol regime; EDEBT, RES in lowvol
D'Agostino and Ehrmann (2014)	tv.par	S	devel	FR,IT spreads: fund's priced before EMU and in fin crisis, not early 00s
Delatte (2014)	reg.ch	S	EZ	fund (debt, fbai, unemp) effect up in EZ periphery
Gibson, Hall and Tavlás (2014)	tv.par	S	Greece	fund effects increase after 2010
Afonso et al. (2015)	roll.r	dS	EZ	fund's more significant in fin crisis, even more in sov crisis
Amstad, Remolona and Shek (2016)	split	(d)S	glob	in crisis global comovements strengthen; loadings determined by ratings and EM dummy
Galaritis, Makrichoriti and Spyrou (2016)	split	dlnS	EZ	econ sent sign. first-part of crisis, but not later; VIX important for periphery (but not core) in crisis
Kallestrup, Lando and Murgoci (2016)	split	S	EZ	bank vulnerability and external debt effect up in crisis
Kocsis and Monostori (2016)	roll.r	(d)lnS	glob	fund effects become smaller, but pol-inst. effects increase after 2012
Paniagua, Sapena and Tamarit (2016)	tv.par	S	EZ	size of effects larger when currency misaligned
Boysen-Hogrefe (2017)	tv.par	S	EZ	since OMT announcement debt ratio effect weakened, institutions strengthened
Reusens and Croux (2017)	split,roll.r	RAT	glob	GDPcap, EDEBT, dgdp,dgdp*debt effect increase, but no break for debt, CA, CPI, DEFhist
Afonso et al. (2018)	tv.par	S	EZ	2007-2011: VIX, BA, debt, ec. sent all becomes signif.; not before, not after
Audzeyeva and Fuertes (2018)	split	S	EM	fund's predictive power sign in crisis, but only institutional after 2013
Bruha and Kocenda (2018)	split	RAT	EZ	banking sector vulnerabilities became more important

Sources: author's compilation.

Notes: The table lists papers that report results concerning the time-varying role of fundamentals within sovereign risk indicators. The second column lists methodologies related to time-variation with the abbreviations: 'split' stands for split samples, 'cr.d' for crisis dummies, 'tv.par' for time-varying parameter models, 'roll.r' for rolling regressions, 'reg.ch.' for regime-switching models. The third column lists the functional form assumed for the dependent variable (S: spreads, RAT: ratings) in regressions. The specifications in differences (e.g. 'dS' or 'dlnS') also include quasi-differenced settings, i.e. regression that include lagged dependents on the right-hand side. The specifications with '(d)' notation refer to estimation of both long-term (levels) and short-term (changes) equations. The fourth column lists the cross-section sample (EZ: eurozone, EM: emerging markets, glob: global, devel: developed countries). The last column summarizes key findings regarding time-variation in effects. For presentation purposes fundamental variable names are abbreviated.

In conclusion, the empirical literature documents that the sovereign risk – fundamentals relationship contains structural breaks on longer time samples that include the global financial and eurozone sovereign crisis. However, different authors found different variables to have had

such changed effects. An often found conclusion of studies evaluating the eurozone experiences is that government debt has become more important in pricing and there is tentative evidence that political-institutional factors have become more important since 2012. Theoretical justification for findings relate to imperfect information and behavioral biases leading to a 'wake-up call' effect or jumps between multiple equilibria due to various possible reasons. An alternative, econometric, explanation for estimated time-variation in effects is that empirical models are misspecified.

PART II

Theoretical modeling and hypothesis development

CHAPTER 5

Theoretical model of sovereign credit risk

The following two chapters set out to develop a sovereign credit risk model with the aim of investigating several channels of fundamental effects on sovereign credit risk. The model is built on the classic endowment economy framework of [Eaton and Gersovitz \(1981\)](#), where the cost-benefit analysis of a rational government results in the default vs repayment decision. Default occurs at the time when the value of default exceeds that of repayment.

The model presented in these chapters is highly stylized. The current chapter focuses only on the single cost-benefit decision of government regarding repayment or default and considers other choices to be exogenous (debt level, debt composition, haircut in default, political economy parameters), while the next chapter considers government choice for long-term values of these parameters. Investors are passive actors in both of these chapters by keeping the real interest rate exogenous. As dynamics and stochastics are suppressed in the model, a comparative statics approach is used.

These simplifications allow the government default/repayment choice to be studied at the wide ranges of empirically observed values for a relatively large set of fundamentals and to keep the model analytically tractable. An important shortcoming of the classic framework is that it restricts attention to two key macroeconomic fundamentals, the level of (external) public debt and real economic growth. This makes the model, in its standard form, inappropriate for studying time-variation in effects of a larger set of fundamentals and their interactions, which may be important to answer how effects vary over time, the ultimate goal of the thesis.

The model considers the default/repayment decision for a large array of model parameters. These parameters are generally considered fixed in time, but are studied in their space of empirically observed/theoretically plausible values (where data are available 5-95 percent intervals are considered) and also in interaction with each other. Their baseline values are evaluated at historical median values and a literature benchmark is calculated for comparison purposes. Using the comparative statics approach, the willingness to repay motivation of the government is analyzed how it changes within the parameters space.

Even though dynamics and stochastics are suppressed, there is one key element in the model of this nature: the government considers default to have a stochastic, potentially crisis-triggering effect. If the crisis is realized the depth of the crisis (its endowment effect) depends on various domestic fundamentals. The range of perceived probabilities for these crisis, the perceived probability of their duration, various fundamental sensitivity measures to crisis are analyzed in detail.

The model proposed in these chapters aims to extend the usual framework that concentrates

on in several directions to capture important missing aspects and determinants of credit risk. Most of these extensions entail features that have been shown to be important by empirical work or that have been rationalized by theorists as discussed in Chapter 2 in detail. The key objective here is to bring the most important (already known) aspects of sovereign risk under one umbrella, so that the model can provide explanations and testable predictions about possible causes of the time variation we see in reduced-form estimates of fundamental effects on credit risk proxies.¹

An extension compared to the classic and the more recent, quantitative, sovereign debt models (e.g. [Aguiar and Gopinath, 2006](#); [Arellano, 2008](#), and many others), which assume external debt finance, is that I also incorporate domestic bondholdings directly into this framework.² The primary concern with omitting domestic debt from sovereign credit risk models is that domestic debt impacts sovereign credit risk in a substantially different way than does external debt. Notably, external-debt-only models disregard a crucial cost of default: haircuts on government securities adversely impact the balance sheet and liquidity of domestic bondholders. As domestic bondholders are often financial intermediaries, sovereign defaults risk a credit crunch with significant adverse repercussions on the macroeconomy. If the government calculates with the possibility of a domestic crisis in case of a default, then larger indebtedness may act to deter strategic defaults and enforce the debt contract. This contradicts standard results of the mainstream sovereign debt literature that posits a positive relationship between indebtedness and credit risk. A corollary of a weaker or even negative relationship between debt and credit risk are high predicted public debt ratios, which is consistent with empirical experience and which is difficult to explain in mainstream sovereign debt models.³ There is now a considerable body

¹The sovereign debt model set out in this chapter incorporates several fundamentals missing from the original framework, but most of these have been studied in detail in other, often highly stylized 2-3 period, models. There are some new features added, but their discussion is kept shorter and a proper elaboration is left for future work. Here, the primary goal is to come up with a useful means to investigate the original question.

²Standard models built on the [Eaton and Gersovitz \(1981\)](#) framework have external creditors supplying funds for government deficit spending, which directly enters current household consumption utility (all endowments are consumed without saving). Defaulting on debt increases utility by the market value of outstanding debt, but it imposes direct or indirect costs, of which classic explanations were exclusion from international markets (loss of reputation) and sanctions (loss of foreign assets or international trade finance). Although this parsimonious external-debt-only framework was well-suited to study developing country debt finance (and especially Latin American debt finance in the 1980s when this literature flourished), domestic public debt was important in both developed and emerging markets in many other periods ([Reinhart and Rogoff, 2011a](#), provides ample historical evidence) and it has played a pivotal role in sovereign credit market stress recently in the financial crisis of 2008-2009 and in the eurozone debt crisis of 2010-2012.

³Authors of sovereign quantitative models need to impose (ad hoc) economic costs in the exclusion period following a default to arrive at plausible sustained debt levels. Without imposing these, the benefits of defaulting would overwhelm the benefits of repayment and, knowing this, investors would never lend to governments. The economic costs proposed in classical models (sanctions, fall in trade credit, market exclusion) were however found to be less relevant empirically, so the more recent studies refer to imposed costs of default as domestic economic costs. However, domestic government debt is non-existent in these models, so these studies need to come up with explanations as to why external debt defaults would adversely impact the domestic economy. [Cole and Kehoe \(1998\)](#) offer the argument that defaults reveal that the government is not trustworthy more generally in its relations, which could lead to reduced investments. Another suggestion by [Mendoza and Yue \(2012\)](#) is that external defaults impair access to international trade and this leads to a productivity shock, because imports are imperfectly substituted domestically. Although these explanations are plausible, the direct impact of sovereign defaults on domestic

of literature that theoretically explains and empirically supports the direct effects of sovereign credit risk on growth through impairment of domestically held bond values.⁴

The model presented in Chapter 5 uses the basic insights of this line of research by adding the possibility of a default-triggered domestic crisis. A central assumption of the model is that if the sovereign chooses to default and the crisis is realized, then the endowment and hence consumption utility is reduced for the duration of the crisis. The intensity of the crisis is assumed to partly depend on the stock of public debt held domestically, the haircut on bonds and a model parameter that is related to both the vulnerability of the banking sector to losses and the importance of the banking sector in the economy.

The second direction in which the classic framework is extended relates to political economy aspects of default. In standard models, a benevolent government is assumed, which decides on default and borrowing with the objective of maximizing domestic consumption utility. The current model allows political preferences to also play a role regarding these decisions.⁵

The political economy extension has two elements in the current model. The first relates to how debt issuance and debt servicing enter the utility function. Whereas external debt trivially affects consumption utility through capital flows (in an endowment economy without savings bond issuance increases current consumption and subsequent debt repayments reduces it), the effect of domestic debt on consumption utility is not straightforward, because domestic bondholders consume less when the debt is issued.⁶ Therefore domestic debt could be viewed as a policy tool for redistribution between investors and taxpayers. In Appendix C.1 I put forward a simple endogenous fiscal policy model along these lines, which relies on a distinction between patient (domestic) investors and impatient voters. Based on this narrative the parameter takes a positive value and net borrowing is utility-enhancing. Other papers (Song, Storesletten and Zilibotti, 2012; Müller, Storesletten and Zilibotti, 2016; D’Erasmus and Mendoza, 2016) also consider distributional effects of domestic debt finance, but from other perspectives. Related to both the political economy and external debt aspects the paper of Broner et al. (2014) discuss implications on the dynamics of the external share of debt when the government wants to

bondholder balance sheets and financial intermediation seems even more natural.

⁴The general mechanism proposed by this strand is that increasing sovereign credit risk erodes financial intermediary balance sheets by destroying the collateral and liquidity value of government securities. This results in reduced bank lending to the private sector, which causes a drop in investment and economic activity (Brutti, 2011; Bolton and Jeanne, 2011; Gennaioli, Martin and Rossi, 2014; Bocola, 2016). The model in Acharya, Drechsler and Schnabl (2014) incorporates also the reverse effect of the deterioration of banking sector strength hitting sovereign credit risk. See Chapter 2 for more discussion.

⁵Again, this idea is not new, the sovereign debt literature has studied political aspects from its early stages. An important benchmark paper that includes political partisanship into the quantitative sovereign framework is Cuadra and Sapriz (2008). See Chapter 2 for more discussion.

⁶This dilemma links to a vast literature that ponders the general value of domestic government debt finance in a closed economy and what explains its existence. Barro (1974) famously argued that debt finance does not alter overall utility, while Barro (1979) highlighted the role of debt finance in tax smoothing. Most models with government bonds held by domestic banks refer to Holmström and Tirole (1998), which rationalizes holding bonds as a store of liquidity. Grobéty (2018) shows that this functionality of government bonds promotes economic growth. This issue is also related to a vast literature on fiscal multipliers, consumer myopia and credit constraints, since these can also rationalize domestic debt issuance. See Chapter 2.

discriminate default between domestic and foreign holders of debt. This model predicts that increasing default risk leads to a larger share of debt being domestically held. The paper [Brutti and Sauré \(2016\)](#) lends empirical support to this theory. (Since the current model has passive investors and does not model secondary markets this element is not incorporated.)

Another political economy parameter represents voter preferences about a repayment/default decision and adds an immediate (positive or negative) value to current utility once default is declared. Repaying debt obligations represents a stance on basic market institutions such as private property rights and are highly valued in advanced economies even without recourse to possible crisis effects of default or redistribution effects between bondholders and taxpayers. At the other extreme, public opinion in countries experiencing default are often hostile toward the market mechanism, international and domestic bond investors, and so: repayment. Obviously, a government interested in enhancing the more general utility of the people that it represents has to consider these preferences in its decision-making.⁷ In the text I discuss plausible values that this parameter can take.

The third direction that the classic [Eaton and Gersovitz \(1981\)](#) model is extended is including the possibility of a government funding liquidity crisis. This is carried out in Chapter 6. In contrast to the standard line of thinking that default leads to market exclusion, here the sequence is reversed: there may be a stop of market funding, which may or may not lead to an eventual default and debt restructuring. The recent crisis in Europe provides ample cases in which governments lost access to private funding markets, but a default was avoided. In the model, if such a funding liquidity crisis is realized, the government has to resort to alternative funding sources (international bailouts and central bank lending of last resort), which is subject to international relations and domestic fundamentals (e.g. central bank reserves and short term funding needs). Fundamentals are not explicitly linked to either the initial funding liquidity crisis probability or the probability of default given such a crisis, but the framework allows this to be done at a later stage.⁸

⁷In most of the discussion I consider this political economy parameter exogenously given – characteristic of the country and time period. At the end of the chapter I briefly explore a more interesting possibility, that government may have an effect on this parameter. Intuitively, if public opinion can be influenced and there is a significant probability that a non-strategic default may occur (default occurs even though repayment has higher value), then the government may be interested in shifting public opinion toward a hostile position on repayments in order to hedge the potential utility loss in case a default is realized. This line of thought resembles a key idea in Galbraith's *The New Industrialist State* ([Galbraith, 1967](#)), in which corporations are assumed to be able to influence consumer preferences through advertisements so that their costly and risky long-term investment projects are met with adequate consumer demand.

⁸This extension relates to a large strand of papers that consider exogenous sources of liquidity shocks and self-fulfilling crises (e.g. [Calvo, 1988](#); [Cole and Kehoe, 2000](#), and others, see Chapter 2). More generally the issue is related to aspects of the ability of sovereigns to repay debt. The mainstream sovereign debt literature preferred the willingness to pay aspect of defaults over the ability to repay due to the (valid) argument that governments usually have larger resources at their disposal to adjust to servicing debt, even though this could be politically unfeasible. Defaults are then a willingness to pay problem except if we consider political limits to fiscal adjustments as exogenously given, in which case the ability to repay aspect becomes relevant. A related idea is fiscal space ([Ghosh et al., 2013](#); [Ghosh, Ostry and Qureshi, 2013](#)). A separate strand on debt renegotiations, market exclusion ([Luo and Wang, 2018](#)) and in particular negotiations of bailouts ([Fink and Scholl, 2016](#); [Roch and Uhlig, 2018](#)) is closely related, since in case of lost market access default usually hinges on the possibility of external assistance.

These extensions notwithstanding, the model still abstracts from salient features of the economy as I keep many of the simplifications in the [Eaton and Gersovitz \(1981\)](#) framework. This is a real economy model that abstracts from prices and monetary phenomena; it is an endowment economy model (no production function, goods or labor market); private savings decisions are also excluded. There have been several papers that discussed sovereign risk in more general frameworks (e.g. [Mendoza and Yue, 2012](#); [Corsetti et al., 2013](#)) and others that discussed relevance of monetary aspects, but the majority of the sovereign risk literature abstracts from these perspectives.

The model presented in the two chapters also has several simplifications compared to other sovereign debt models that are built on the classic framework. Most of these simplifications are relaxed in an extension of this model in Appendix C.2 and are needed here to convey the key messages in a relatively simple framework that is already able to account for most relevant fundamentals either explicitly linked into the model or implicitly through model parameters. Appendix C.2 shows that results are robust to these extensions.

First, I separate the government decision-making regarding borrowing from the decision about defaulting on debt. The focus in much of the analysis is on the default decision though I will turn to the borrowing decision briefly in Section 6.4. These decisions are jointly handled in the mentioned literature and will also be jointly determined in Appendix C.2.

The second simplification is that dynamics are restricted to a near static framework in this chapter. Such restrictions are not unusual in the sovereign risk literature as several authors use two- and three-period stylized models (e.g. [Acharya and Rajan, 2013](#); [Brutti, 2011](#); [Ghosal and Miller, 2003](#)) and even in the infinite-horizon quantitative strand such simplification is sometimes used for proof of concept (e.g. [Arellano and Ramanarayanan, 2012](#)). The model in this chapter has the sovereign decision on default brought at the beginning of the first period, which (together with state of nature) jointly determine expected outcomes of a short-term period with potential crisis (1-100 years) and the long-term (following the short-term to infinity), in which no crisis is assumed. Although the horizon is infinite, there are basically two distinct periods analyzed in the model.

Stochastics are also significantly limited in the model to keep the analysis focused and tractable. Notably, the short-term period exhibits probabilities regarding four states of nature (normal and different types of crisis). Several fundamentals are assumed to be fixed across these states of nature and policy states of repayment and default, while others may vary across these states. An important restriction is that real interest rates are considered to have only two states (normal and crisis) exogenously given and fixed within each period. Appendix C.2 endogenizes interest rates.

The model is investigated within the parameter space that aims to characterize a large sample of emerging and developed economies. This is more general compared to the extant quantitative literature, which mainly calibrates its parameters to the experience of Argentina. Argentine data

Closest to the line of thought in my model is a recent paper by [Bølstad and Elhardt \(2017\)](#).

may successfully represent several Latin American experiences, but it is significantly different from many other countries, especially middle-income emerging markets and developed countries where defaults are rare. Identifying plausible parameter bounds and baseline values is a central part of the chapter, because this provides a means to discern which channels of fundamental effects already assumed by the model setup may be more or less relevant in reality. Most importantly, these parameter bounds and baseline values provide a tool to evaluate how fundamental interactions influence sovereign risk and whether these effects are different in normal and crisis times. These are important for the general objective of the thesis, because reduced-form empirical models usually do not take interactions into account,⁹ which could be a plausible reason for observed time-variation in estimated effects.

The structure of the chapter is as follows. Section 5.1 describes the basic modelling framework including its assumptions and some implications for SDV, the strategic default value: the relative value of default over repayment.¹⁰ Section 5.2 discusses parameter baseline values and allowed bounds. It also provides estimates and discussion of SDV with parameters set to the baseline values versus parameters set to literature benchmark values.

Section 5.3 turns to the main topic of the thesis and describes how fundamental parameters affect SDV. Some analytical results are provided and are related to the literature. A key result, at odds with the mainstream classic and quantitative sovereign literature, is that in this model indebtedness does not necessarily increase strategic default risk. In fact, at the baseline (most plausible) values, it reduces the credit risk due to strategic considerations. Section 5.3 also provides an analysis of variable interactions and non-linearities related to different fundamental - SDV relationships under normal and crisis regimes.

5.1 General model specification (Model I)

I consider a model of sovereign debt in an endowment economy, where the government can borrow from both external and domestic investors. As commonly assumed: markets are incomplete (government cannot insure against uncertainty), repayment is a sovereign decision and the government cannot pre-commit to repaying debt. The government is viewed as a (bounded) rational agent that optimizes a utility function to decide on the level and structure of debt and to bring decisions about default vs repayment.¹¹

The government optimizes by considering the following utility function:

⁹Given the large number of potential fundamentals, there would be an infeasible number of factor combinations, so a theoretical model is needed for guidance in selecting relevant interactions. The extant theoretical literature does not help in this regard and the current model aims to fill this gap.

¹⁰SDV is a shorthand for the value difference between default and repayment, which determines whether a strategic default occurs. Other papers do not use a separate name for the difference, but rather write out $V^B - V^G$ for bad and good credit standing values or $V^D - V^R$ for values of the default and repayment policy explicitly. Introducing SDV is for notational ease, since the difference is used more often than its constituents.

¹¹The bounds on government rationality consists in government considering only one default decision and not calculating with the possibility of repeated defaults. In the quantitative model in Appendix C.2 this assumption will be relaxed and government is assumed fully rational and forward-looking in that setting.

$$U^{govt} = \sum_{t=1}^{\infty} \beta^{t-1} u_t^{govt}(c_t^{hold}, \Theta).$$

Government utility is closely related to household consumption utility (it is standard in the sovereign risk literature to assume benevolent governments that maximize representative household consumption utility), but is more general than that as it is viewed in a political economy context representing the preferences of political agents in government to remain in power. Household utility enters government utility, because welfare of domestic households in the voting constituency is beneficial for the bid to power. As later described, there are some important points, where it is useful to make the distinction between household and voter (i.e government) utilities.

5.1.1 Borrowing decision

Borrowing and default/repayment decisions are separately handled in periods $t = 0$ and $t = 1$, respectively. (This chapter deals with the default decision, and section 6.4 turns to the borrowing decision.) The government does not calculate with any future decisions after $t = 1$.¹²

Government decides on the level of borrowing (debt ratio d) and the share of external issuances (ψ) in $t = 0$.

$$U_0 = \max_{d, \psi} \left\{ \sum_S \pi_S E_0[U_S(d, \psi)] \right\}$$

To bring this decision the government maximizes its utility function with respect to these variables. Utility in this period is based on the expectation of probability-weighted state-utilities U_S for initial states $S = \{N, C\}$ (normal or crisis) not yet realized, but its probabilities, π_S , known. Government is assumed to calculate with keeping the debt ratio, external share of debt and maturity structure constant in the future with the only exception of a one-time reduction in the debt ratio in case of defaulting in period $t = 1$.

It is worth to stop and discuss the constant future debt ratio assumption in more detail, because the decision about debt dynamics is a centerpiece of the sovereign debt literature. A benefit of this assumption is that it greatly simplifies analysis and allows studying the effects of many fundamentals and parameters, which is important for the thesis. My assumption restricts cyclical fiscal policy,¹³ but empirical evidence on such systemic policy reaction is mixed¹⁴ and

¹²In quantitative model these decisions are brought simultaneously and future decisions are taken into account.

¹³It allows some automatic business cycle smoothing as I define the constant debt ratio in terms of trend GDP: in a downturn trend GDP is above current GDP and thus debt/GDP increases relative to debt/trend GDP. Intuitively, this may be seen as letting automatic stabilizers operate (countercyclicality), while turning off additional discretionary measures to combat a recession.

¹⁴As covered in Chapter 2 most emerging market evidence points to procyclicality, whereas developed countries tended to be countercyclical.

consumption smoothing turns out to be of secondary importance in calculations of debt levels¹⁵ and in determining consumption utility in general (Lucas, 1987). Still, the possibility of expected trend increases in the debt ratio could be important and disregarding this feature is a limitation of the model considered here. However, permitting fully flexible debt dynamics, as done in standard sovereign models, constitutes another unrealistic extreme, which disregards the fact that governments can (and do) only alter the debt ratio gradually. The possibility of huge swings in debt ratios influences default predictions, because it leads to an unrealistically high benefit of default. Slower paced debt increases would have smaller utility benefits due to the temporal discounting of future consumption.¹⁶ Reality is likely to lie in between the extremes of fixed debt ratios considered here and the fully flexible debt ratios considered elsewhere and Appendix C.2 aims to strike a balance by permitting changes in the debt ratio within plausible bounds.

As mentioned in the introduction to the chapter, an important difference compared to the mainstream of the sovereign debt literature is that I add the possibility of domestic bondholdings. Domestic bonds decrease the value of defaulting as they could adversely impact domestic bank (or more generally household) balance sheets, which reduces utility.

Although domestic bonds help explain large default costs, it is not straightforward to explain the existence of domestic public debt in the first place. In standard models external capital inflows lift current consumption and therefore trivially raises the utility of impatient domestic consumers. With domestic debt finance, however, the (benevolent) government also needs to lenders. When issuing bonds domestically, this reduces current consumption of domestic investors, whereas it increases consumption of beneficiaries of government deficit spending. Further, models set in a domestic arena usually endogenously determine real interest rates, which revert to average subjective discount rates (so that both match marginal product of capital). Then, benefits of current consumption are offset by future increased taxation and the Ricardian equivalence result holds as proposed by Barro (1974): domestic bond issuance does not have any added utility.

There are several avenues of theory that rationalize the existence of domestic debt finance. First, Ricardian equivalence may still fail due to fiscal illusion and myopia of consumers, and

¹⁵E.g. Aguiar and Gopinath (2006) shows that cyclical policy could account for a maximum of 8-9 percent debt ratio in the case of Argentina. The supported debt would be even smaller in other countries with lower output volatility.

¹⁶In the canonical models of Aguiar and Gopinath (2006) and Arellano (2008) the debt ratio can theoretically vary from 0 to the maximum considered amounts from one period to the other (i.e. within three months), with a preference for smooth consumption supplying the only brakes on this process. In fact these models do predict that after default and temporary exclusion from debt markets, debt will immediately jump up to ranges close to the sustainable levels in these models (25-70 percent of GDP). The capital inflow due to this jump in debt is the key payoff of the default policy. However, it is highly unlikely that any government (especially one just emerging from default) could increase its debt ratio by such amounts without instigating a debt crisis by signalling complacency. Glossing historical debt data a large majority of debt ratio changes lie within the +/-5 percent range. The occasional abrupt swings (e.g. over 10 percentage points) in the debt ratio are mostly due to unforeseen declines in GDP (natural catastrophes, wars) or swings in debt valuation due to currency crises or hyperinflation, which leaves less role for net issuance decisions. The reason for the slow changes in debt ratios is that a large drop in net issuance involves politically unfeasible tax rises and large increases would signal irresponsible fiscal policy and would increase funding costs.

a share of households being credit-constrained. Then, the government can borrow on behalf of credit-constrained individuals. Domestic debt may also have a benefit for the functioning of the financial system as it enhances liquidity (Holmström and Tirole, 1998). Finally, political economy explanations account for the deficit bias by portraying government politicians as rent-seekers or pointing out factors, which hinder balancing the budget (e.g. Alesina and Tabellini, 2005, and many others, see Chapter 2). On the other hand, theoretical arguments on fiscal spending crowding out domestic investments and hence lowering future long-term growth constitute counterarguments for running up debt and saving instead.

Another, alternative explanation that I put forward in Appendix C.1 is based on the difference of time preferences of the representative voter and the marginal investor.¹⁷ Underlying this idea is the well-documented fact of uneven wealth distributions: the majority of wealth is owned by a small fraction of society and a larger segment is closer to being hand-to-mouth spenders (e.g. Mankiw, 2000; Boldizar et al., 2016, for U.S and Hungarian evidence, respectively). Further, low income households are also shut out from credit markets. It seems then, that real interest rates will be determined by the average discount rates of the wealthier layers of society and not by the relevant representative voters. Assuming (as standard) that lower income households are more impatient, the discount rate that governments have to consider must be lower than that consistent with real interest rates. The optimal debt size increases in impatience of the relevant representative voter compared to the marginal investor; the time horizon that agents plan on; and the quality of public services (the higher value of public to private goods and the lower the tax distortions).

5.1.2 Default decision

In period $t = 1$, the economic state S is realized and d, ψ are given, when government decides whether to default¹⁸ i.e (i) to repay and roll over the full outstanding debt amount in the future or (ii) default and renegotiate the debt taking a haircut of h^g and rolling over debt with the new debt ratio indefinitely.¹⁹

¹⁷This fiscal policy model is relegated to Appendix C.1 and is not elaborated in more detail, because the borrowing decision is not the central focus of the thesis. The fact that domestic debt exists and is a significant phenomenon (which is trivial empirically) is already enough reason to include it in sovereign credit risk calculations. The model nonetheless shows a novel explanation why domestic debt arises without discarding the benevolent government assumption or rationality of actors. It also shows a reason why fiscal deficits may continually be utility-enhancing (even if anticipated), which is not evident with fiscal multipliers. Weakening the arguments of this model is a line of empirical political economy research (Alesina et al., 1998; Eslava, 2011; Brender and Drazen, 2008), which claim that voters do not favor expansionary fiscal policies. However, there are several counterarguments questioning the relevance of these empirical findings. (See Appendix C.1).

¹⁸I use the terms default and defaulting universally for credit events that involve debt repudiation (strategic non-payment) and missed payments due to liquidity shortfalls.

¹⁹In the first part of the chapter I use the term haircut referring to a face value debt reduction and assuming it equals investor losses (as calculated by e.g. Sturzenegger and Zettelmeyer, 2006; Cruces and Trebesch, 2013). In the second part of the chapter I consider debt relief (face value reduction) and investor losses separately. I consider an exogenous determination for the haircut throughout and only take a brief detour at its choice in section 6.4.

5.1.3 Assumptions

Overall, the model assumes 6 different states: $\{N^R, C^R, N^D, C^D, N^D, C^D\}$ with superscripts (R, D) standing for repayment or default policy states and subscripts denoting initial (N, C) and post-default (n, c) states of nature, which completely determine all elements of payoffs. Since the initial state $S(N, C)$ is realized at this period, the utility function has components related to the repayment value in state S and the default values in post-default states s :

$$U_S = (1 - \lambda)V_S^R + \lambda \sum_s \pi_s V_{Ss}^D.$$

Period-by-period payoffs of the realized state are aggregated with utility function $u(\cdot)$ and discounted by government discount factor β to form overall value functions for each state. As usual: overall utility is assumed time- and state-separable and concave. I will assume logarithmic utility. Keeping with the literature I assume that arguments of the utility function, v , are positive in each state and time period.²⁰

In case of repayment, utility is determined by domestic household consumption, which in turn is given by an exogenous output endowment (Y_S^R) plus net foreign borrowing from abroad (NFB), and a term related to the effect of the fiscal balance (overall net borrowing) on consumption and voter utility ($\alpha_1 NB$).²¹

$$V_S^R = \sum_{t=1}^{\infty} \beta^{t-1} u(v_{S,t}^R) = \sum_{t=1}^{\infty} \beta^{t-1} u(Y_{S,t}^R + NFB_{S,t}^R + \alpha_1 NB_{S,t}^R).$$

In the default case, utility has similar household consumption elements, but it also has a one-time, first-period political utility element of magnitude α_2 (positive if voters favor a default). Further, with probability π_c the default decision triggers a crisis state $s = c$ (denoted with lowercase to differentiate from the initial economic state). The default-triggered crisis has a negative effect on growth rate in the initial period and has a continuous effect on output keeping the output gap open until it lasts. The output loss is larger the larger is the domestically held debt and the haircut, consistent with the view, that the domestic banking system is the key holder of domestic government securities and that adverse balance sheet impacts result in reduced lending and an output loss. The crisis is also assumed to raise the real interest rate.

²⁰This is a standard assumption of the literature that ensures a well-behaved utility function and is an effective restriction only at extreme parameter choices (basically any reduction of utility is restricted to be at most the size of trend output).

²¹The mainstream sovereign credit risk models that consider an endowment economy with external creditors calculate with the first two terms. Fiscal balances may be argued to affect utility on the grounds of fiscal illusion, household myopia and/or credit constrained households; positive liquidity effects of domestic debt (positive value for α_1) or considering unfavorable long-run growth effects (without modeling these explicitly in the endowment stream: negative value for α_1). The model presented in Appendix C.1 provides an alternative explanation for fiscal deficits reducing utility, because debt service decreases the value of public goods on the margin more than it raises utility of private goods. The empirical evidence of debt on long-term growth is mixed (see Chapter 2). Fiscal multipliers on the other hand appear to have a short-term effect, but effects of anticipated shocks would be hard to justify.

$$V_{Ss}^D = \alpha_2 + \sum_{t=1}^{\infty} \beta^{t-1} u(v_{Ss,t}^D) = \alpha_2 + \sum_{t=1}^{\infty} \beta^{t-1} u(Y_{Ss,t}^D + NF B_{Ss,t}^D + \alpha_1 N B_{Ss,t}^D).$$

The mainstream approach assumes a period of autarky on the sovereign following a default and often full debt repudiation is also assumed. In line with historical experiences, I instead assume partial repudiation and that the new (lower, but positive) debt ratio is upheld, which involves continued interaction with the bond market, because there are interest payments and debt is rolled over (restructured). Bond investors and official creditors often agree to lengthening maturities of outstanding bonds (technically: switching to new long maturity bonds from short-term bonds they hold), which practically means continued access to their funds – even if there are no new bond issues taking place (the usual proxy for debt exclusion). A default also reduces funding need due to alternative funding sources (international bailout, asset sales). These usually constitute cheaper funding than new bond issuances would, and therefore there may be a lack of demand for private market access on part of the sovereign, not only a lack of market funding supply – as commonly argued. All these elements are seen in the Greek crisis for instance.²²

If a strategic default is declared, with probability $1 - \pi_c$ the default-triggered crisis is avoided in state $s = n$. This state resembles the repayment state with the difference that debt relief and α_2 , the political economy utility element of a default, are realized.

The above assumptions are collected and summarized in Assumption 5.1.

Assumption 5.1. (*Government utility*)

$$\begin{aligned} U_0 &= \max_{d, \psi} \left\{ \sum_S \pi_S E_0[U_S(d, \psi)] \right\}, & U_{1|S,d} &= \max_{\lambda^g, h} \{ E_0[U_S|S] \}, \\ E_0[U_S] &= (1 - \lambda) V_S^R + \lambda \sum_s \pi_s V_{Ss}^D, \\ V_S^R &= \sum_{t=1}^{\infty} \beta^{t-1} u(v_{S,t}^R) = \sum_{t=1}^{\infty} \beta^{t-1} u(Y_{S,t}^R + NF B_{S,t}^R + \alpha_1 N B_{S,t}^R), \\ V_{Ss}^D &= \alpha_2 + \sum_{t=1}^{\infty} \beta^{t-1} u(v_{Ss,t}^D) = \alpha_2 + \sum_{t=1}^{\infty} \beta^{t-1} u(Y_{Ss,t}^D + NF B_{Ss,t}^D + \alpha_1 N B_{Ss,t}^D), \\ S &\in \{N, C\} & s &\in \{n, c\}, \\ 0 &\leq v, v + \alpha_2, \end{aligned}$$

where d, ψ are debt ratio, share of external debt; λ^g is the default choice, λ may be more generally the state of default (value of 1 in default, 0 otherwise), h is the haircut; S, s, π_S, π_s are initial and post-default states of nature and their probabilities; $u(\cdot), v, \beta$ are utility function, voter pay-

²²Details of renegotiations are not modelled here. See references on this literature strand in Chapter 2. In Chapter 6 I change some of these assumptions when incorporating a funding liquidity crisis into the model. In that type of crisis government loses market access and is forced to request alternative funding (bailout). Note that this market exclusion is different from exclusion in other models as it precedes or does not even entail debt default and is in line with a number of examples in the eurozone periphery and emerging markets during the 2008-2012 period.

offs and subjective discount factor, respectively; α_1 and α_2 are political economy parameters; Y , NFB , NB represent output endowment, net foreign borrowing and net borrowing.

The endowment Y is assumed to be growing at a constant trend growth rate of $\bar{g}$ in the normal state. Let lowercase letters stand for variables normalized by the initial Y_0 output. Then, the endowment stream $\{y_0, y_1, y_2, \dots\}$ is $\{1, (1 + \bar{g}), (1 + \bar{g})^2, \dots\}$. If the initial state is $S = C$, the endowment deviates from trend by a ratio g_C in the periods $t = 1 \dots T$ from which time output switches back to the initial trend. In terms of growth rates: there is a first-period adverse shock and a period T positive shock. For instance, if crisis hits the first two periods, the endowment stream would be $\{1, (1 + \bar{g} - g_C), (1 + \bar{g})(1 + \bar{g} - g_C), (1 + \bar{g})^3, \dots\}$. Crises (compared to normal endowment) therefore have a cumulative output loss equal to $g_C ((1 + \bar{g}) + \dots + (1 + \bar{g})^T)$ in terms of the initial output. Also, period-on-period growth rates are such that $g_t = \bar{g}$ for all periods except $g_1 = \bar{g} - g_C$ and $g_{T+1} = (\bar{g} + g_C + \bar{g}^2) / [1 + \bar{g} - g_C]$.^{23,24}

If a default-triggered crisis occurs, the payoff for the given period is reduced by $g_c = \nu_1 + \nu_2(1 - \psi)hd$ for periods T (on top of potential output losses of the initial crisis state). Parameters ν_1 and ν_2 can be understood as an unconditional endowment shock and an endowment reduction conditional on the haircut on bonds owned by residents.²⁵ Again, these parameters can also be interpreted more broadly as representing a general political economy value due to voter disutility.²⁶

Assumption 5.2. (Endowment stream)

$$\begin{aligned} g_c &= [\nu_1 + \nu_2 d(1 - \psi)h], \\ g_{Ss} &= 0 + 1_{\{S=C\}}g_C + 1_{\{\lambda=1, s=c\}}g_c, \\ \tilde{Y}_t &= \tilde{Y}_{t-1}(1 + \bar{g}_t) = Y_0(1 + \bar{g})^t, \\ G_{Ss,t} &= \begin{cases} \frac{1 + \bar{g} - g_{Ss}}{1 + \bar{g}}, & \text{if } t \leq T, \\ 1, & \text{if } t > T, \end{cases} \end{aligned}$$

²³To see this: $Y_{T+1}/Y_T = (1 + \bar{g})^{T+1} / [(1 + \bar{g} - g_C)(1 + \bar{g})^{T-1}] = (1 + \bar{g})^2 / [1 + \bar{g} - g_C]$ using the assumptions about the endowments. The growth rate in $T + 1$ is $Y_{T+1}/Y_T - 1 = (1 + 2\bar{g} + \bar{g}^2 - 1 - \bar{g} + g_C) / (1 + \bar{g} - g_C)$. Simplifying gives the result for g_{T+1} .

²⁴The assumption of terminal reversion to the initial trend results assumes no hysteresis effects and results in a terminal jump in output consistent with a Phoenix recovery narrative (Calvo, Izquierdo and Talvi, 2006). Whether this is a realistic assumption can be debated but admitting a large maximum value for T allows studying the hysteresis case.

²⁵As reviewed in Chapter 2, several empirical studies found support for domestic economic output costs being relevant in defaults. One such channel for output costs is associated with the domestic financial sector experiencing liquidity or balance sheet shocks due to its holdings of government securities (e.g. Gennaioli, Martin and Rossi, 2014; Acharya, Drechsler and Schnabl, 2014, and others), which would imply the severity of default costs increasing with debt ratio, the domestically held share of debt and the haircut. A recent paper by Romer and Romer (2017b) also supports the view that output losses are larger when there is larger debt outstanding in a crisis.

²⁶For instance, before or immediately after a default decision there is bound to be a heated domestic political debate about whether such a move is good for the country. If a crisis ensues, this vindicates the opposition, which will have a political cost. If it does not, it vindicates the government.

$$Y_{Ss,t} = \tilde{Y}_t G_{Ss,t},$$

$$0 \leq g_C, \nu_1, \nu_2$$

where $\bar{g}$ is the trend growth rate of the endowment, g_{Cc} is the first-period endowment growth rate that may also include crisis components: the initial state crisis has a component of g_C , the default-triggered crisis is determined by ν_1, ν_2 parameters, domestically held bonds and the haircut. G_{Ss} relates first period growth to trend growth (and is the output gap while the crisis lasts). $Y_{Ss,t}$ is state dependent output in time t , $\tilde{Y}_t$ is trend output.

In the repayment regime the structural debt ratio ($d = D/\tilde{Y}$, the nominal debt to trend growth) is assumed to remain fixed, whereas in the default regime the structural debt ratio decreases by a fraction h (haircut or debt relief) and this ratio is maintained thereafter. The external share of debt is assumed constant.

Bonds are assumed to be one-period (one year) zero-coupon bonds, so each period the full debt, $\tilde{Y}_{t-1}d$, matures (at both notional and market value). To keep the structural debt ratio constant new bonds have to be issued with total notional of $\tilde{Y}_{t-1}d\bar{g}$,²⁷ with a price of q_t . Overall government net borrowing then amounts to $\tilde{Y}_{t-1}d(q_t\bar{g} + q_t - 1)$ in each period. The structural fiscal deficit is equal to this expression (the first term is the structural primary balance, the last two relate to debt service). Net foreign borrowing is net borrowing multiplied by ψ (the external share of debt). Using real interest rates instead of real bond prices ($q_t = 1/(1 + r_t)$), net borrowing is $\tilde{Y}_{t-1}d(\bar{g} - r_t)/(1 + r_t)$.

In case of a default, net foreign borrowing is simply reduced proportionately by $1 - h$, because both oncoming obligations are reduced by this amount for all maturities and issuances also follow the new, smaller debt amounts.²⁸ The key benefit of default thus derives from the utility effects of a reduction of future and current debt service. This is a somewhat different way of viewing the benefit of default compared to the classic literature, which values default simply by the market value of debt outstanding²⁹ and also compared with the quantitative literature that values default in terms of net capital inflows, primarily through the jump in debt levels back to pre-default levels after a short period of autarky.³⁰

²⁷With the structural debt ratio constant: $d = D_t/\tilde{Y}_t = D_{t-1}/\tilde{Y}_{t-1}$ so that $\tilde{Y}_{t-1}D_t = D_{t-1}\tilde{Y}_t$ and $D_t = D_{t-1}(1 + \bar{g})$ using $\tilde{Y}_t = \tilde{Y}_{t-1}(1 + \bar{g})$. Then, $\Delta D_t = D_{t-1}\bar{g} = d\tilde{Y}_{t-1}\bar{g}$.

²⁸Technically, debt forgiveness appears in the capital account, whereas actual capital flows related to borrowing and repayment appear in the financial account of the balance of payments. The model here concentrates on these latter capital flows and I use the term net foreign borrowing to avoid the ambiguity of the term 'capital flows' in case of a default.

²⁹See for instance [Eaton and Gersovitz \(1981\)](#) or [Edwards \(1983\)](#). The present value of forgiven future debt payment cash flows (in classic models: the full amount) sum up to the value of debt. However in the current model the presence of domestic debt and possibility of agents with different intertemporal elasticities cause the value felt by the representative voter (taxpayers) to deviate from market values of debt.

³⁰[Stähler \(2013\)](#) provides a summary of such models. Again, I claimed that it is unrealistic to think that a government on the verge of default (that plausibly has significant disputes with external creditors at the time) would seriously consider the utility of running up debt after a period of exclusion. Governments are dynamically inconsistent in this sense: later, they would probably still increase debt, but it is unrealistic to assume governments to calculate with this increase. Investors would probably also not offer the amount of credit at such pace that these

The following set of equations summarize the above assumptions.

Assumption 5.3. (*Fiscal and current account balances*)

$$NB_t^R = \tilde{Y}_{t-1} \frac{d(\bar{g} - r_t)}{1 + r_{Ss,t}} = \tilde{Y}_t \frac{d(\bar{g} - r_{Ss,t})}{(1 + r_{Ss,t})(1 + \bar{g})},$$

$$NB_t^D = (1 - h)NB_t^R, \quad NFB_t^R = \psi NB_t^R, \quad NFB_t^D = \psi NB_t^D,$$

where NB_t , NFB_t measure net borrowing (structural fiscal deficit) and net foreign borrowing (positive values consistent with capital inflow), respectively, and r_t is the yield on the one period zero-coupon bond priced in the period t .

Real interest rates (the nominal risk free rate plus various premia minus inflation) are assumed to be fixed in the current and next chapter. In quantitative models of sovereign credit risk the bond price q is given by $q = (1 - \lambda h)/(1 + r^f + RP)$ and thus the real interest rate is $r = (1 + r^f + RP)/(1 - \lambda h) - 1$. In the quantitative model of Appendix C.2 I will turn to such a standard, fully endogenized version of real interest rates, where credit risk spreads of interest rates are determined endogenously by default probabilities.

Here, however, I take a simplified view of interest rates and assume that they are different under normal and crisis episodes. This non-behavior of investors is admittedly a weakness of the current model.

Assumption 5.4. (*Real interest rate*)

$$r_{Ss,t} = \begin{cases} r_C, & \text{if } t \leq T, Ss \in \{Cn, Nc, Cc\}, \\ r, & \text{otherwise,} \end{cases}$$

where r_C is a crisis state real interest rate and r is the normal state real interest rate.

5.1.4 Strategic default value (SDV)

The strategic default decision is the cost-benefit calculation of government about the relative value of default versus that of repayment. By Assumption 5.1, the government will choose default, when the utility of repayment is lower than that of default. Due to their importance for the thesis I state these concepts explicitly in the following definitions.

Definition 5.1. $SDV_S = V_S^D - V_S^R$ is the relative value of strategic default in the state of nature S .³¹

models suggest.

³¹If the utility function is differentiable by λ^g , then SDV can be interpreted as the partial derivative of the utility function with respect to the default decision parameter λ^g . In fact in the binary choice case, SDV is the slope of the interpolated line between points $(1, V^D)$ and $(0, V^R)$.

Definition 5.2. Strategic default is the policy decision of government to default because expected utility choosing default is higher than the expected utility of the repayment choice.

At the beginning of period $t = 1$ the government information set contains the initial state of nature $S \in \{N, C\}$. The following expressions describe utility in the initial state S :

$$U_S = (1 - \lambda^g)V_S^R + \lambda^g(1 - \pi_c)V_{Sn}^D + \lambda^g\pi_cV_{Sc}^D. \quad (5.1)$$

Using definition 5.1, the strategic default value in each state is:

$$SDV_S = -V_S^R + (1 - \pi_c)V_{Sn}^D + \pi_cV_{Sc}^D. \quad (5.2)$$

Based on the policy function in Assumption 5.1 and definition 5.2 strategic default occurs in period 1, if $SDV_N > 0$ in state N and $SDV_C > 0$ in state C .

5.1.5 SDV components

As mentioned before, the model accommodates two states of nature in the repayment regime $Ss \in \{Nn, Cn\}$ and four states of nature in default $Ss \in \{Nn, Cn, Nc, Cc\}$. Denote the government decision states of default or repayment (as in Assumption 5.1) using $\lambda^g = 1$ for the default choice and $\lambda^g = 0$ for repayment.

By substituting Assumption 5.2 and Assumption 5.3 into Assumption 5.1 the value functions can be compactly written for each of these states as:

$$\begin{aligned} V_{Ss}^{R/D} &= \lambda^g \alpha_2 + \sum_{t=1}^{\infty} \beta^{t-1} \log \left[Y_0(1 + \bar{g})^t A_{Ss,t}^{R/D} \right], \\ A_{Ss,t}^{R/D} &= \tilde{G}_{Ss,t} + d(1 - h\lambda^g) \frac{(\psi + \alpha_1)(\bar{g} - r_{Ss,t})}{(1 + \bar{g})(1 + r_{Ss,t})}. \end{aligned} \quad (5.3)$$

The value function consists of the default (political economy) benefit α_2 and the stream of discounted endowments corrected by the value of net borrowing. The corrected endowment stream is written in terms of trend output $\tilde{Y}_t = Y_0(1 + \bar{g})^t$ with correction term $A_{Ss,t}^{R/D}$. The correction consists of modification of trend output to the actual endowment level by the output gap $\tilde{G}_{Ss,t}$ (Assumption 5.2) and net borrowing (which is in terms of trend output) as specified in the second term (Assumption 5.2). Handling $A_{Ss,t}^{R/D}$ separately simplifies the discussion, because trend output is independent of the state.

Based on Assumption 5.2 and Assumption 5.4 the endowment and real interest rates, $\tilde{G}_{Ss,t}$ and $r_{Ss,t}$, depend on the state of nature until time period T , after which point however, both output and real interest rates are assumed to return to the normal state. It makes sense therefore to split the value functions into two parts:

- the short-term ($t \in \{1, \dots, T\}$), and

- the long-term ($t \in \{t : t \geq T + 1\}$) component.

The short-term and long-term components of total utility will be denoted as $V^{(1)}$, $V^{(2)}$, respectively, and endowment corrections by $A^{(1)}$ and $A^{(2)}$.

The short-term crisis states entail a change in the endowment (due to g_{Cc}) and the real interest rate (r_C). In the default regime the debt ratio is reduced by a factor $h\lambda^g$ and a one-off political economy utility effect of default, α_2 , is realized.

The endowment stream in equation (5.3) can be rearranged into:

$$\sum_{t=1}^{\infty} \beta^{t-1} \log \left[Y_0 (1 + \bar{g})^t A_{Ss,t}^{R/D} \right] = \log \left[Y_0 A_{Ss,t}^{R/D} \right] \sum_{t=1}^{\infty} \beta^{t-1} + \log(1 + \bar{g}) \sum_{t=1}^{\infty} t \beta^{t-1} \quad (5.4)$$

The terms $\log[Y_0 A_{Ss,t}^{R/D}]$ and $\log(1 + \bar{g})$ do not change within the short-term or the long-term period and thus the above expression consists of two power series.

In the first T periods the series are $\sum_{t=1}^T \beta^{t-1} = \frac{1-\beta^T}{1-\beta}$ and $\sum_{t=1}^T t \beta^{t-1} = \frac{1+T\beta^{T+1}-(T+1)\beta^T}{(1-\beta)^2}$. Using these formulas the short-term subutilities then sum up to:

$$\begin{aligned} V_{Ss}^{(1)R/D} &= \sum_{t=1}^T v_t = \frac{1-\beta^T}{1-\beta} (\log Y_0 + \log A_{Ss}^{(1)R/D}) + \frac{1+T\beta^{T+1}-(T+1)\beta^T}{(1-\beta)^2} \log(1 + \bar{g}), \\ A_{Ss}^{(1)R/D} &= \tilde{G}_{Ss,t} + (1 - h\lambda^g) d \frac{(\psi + \alpha_1)(\bar{g} - r_{Ss,t})}{(1 + r_{Ss,t})(1 + \bar{g})}. \end{aligned} \quad (5.5)$$

A key implication of model assumptions is that after period T the endowment and other parameters are the same for both normal and crisis states. The only differences that remain between the policy choices of repayment or default are in the debt ratios. The presentation of long-term components is simpler when the endowment stream is rewritten in terms of $\tilde{Y}_T$, which is thus the common starting point for endowment streams after T for each state, just like Y_0 was for the full endowment stream. Then, the value function is $\sum_{t=T+1}^{\infty} \beta^{t-1} \log(Y_t A)$ or $\beta^T \sum_{t=1}^{\infty} \beta^{t-1} \log[Y_T A (1 + \bar{g})^t]$ so the discount factor series (given the assumption $|\beta| < 1$) are $\beta^T \sum_{t=1}^{\infty} \beta^{t-1} = \frac{\beta^T}{1-\beta}$ and $\beta^T \sum_{t=1}^{\infty} t \beta^{t-1} = \frac{\beta^T}{(1-\beta)^2}$. The long-horizon items of utility have the following value function:

$$\begin{aligned} V^{(2)R/D} &= \frac{\beta^T}{1-\beta} (\log Y_{T+1} + \log A^{(2)R/D}) + \frac{\beta^T}{(1-\beta)^2} \log(1 + \bar{g}). \\ A^{(2)R/D} &= 1 + (1 - h\lambda^g) d \frac{(\psi + \alpha_1)(\bar{g} - r)}{(1 + r)(1 + \bar{g})}, \end{aligned} \quad (5.6)$$

Subutilities in both short- and long-term periods include additive logarithmic terms of initial output and discounted growth rates, which are the same in both repayment and default states and hence cancel out in SDV . Using equation (5.2) SDV can be written for the normal and crisis states in the short-term and the long-term state (there is no crisis there) as:

$$\begin{aligned}
SDV_N^{(1)} &= \frac{1 - \beta^T}{1 - \beta} \left(-\log A_{Nn}^{(1)R} + (1 - \pi_c) \log A_{Nn}^{(1)D} + \pi_c \log A_{Nc}^{(1)D} \right) + \alpha_2, \\
SDV_C^{(1)} &= \frac{1 - \beta^T}{1 - \beta} \left(-\log A_{Cn}^{(1)R} + (1 - \pi_c) \log A_{Cn}^{(1)D} + \pi_c \log A_{Cc}^{(1)D} \right) + \alpha_2, \\
SDV^{(2)} &= \frac{\beta^T}{1 - \beta} \left(-\log A^{(2)R} + (1 - \pi_c) \log A^{(2)D} \right). \tag{5.7}
\end{aligned}$$

Informally, strategic default has the potential upside from $\log A$ terms and parameter α_2 . The A term contribution to SDV depends on several factors and chiefly on how debt servicing is related to utility. In the cases considered here $\psi + \alpha_1$ is positive, so A is mainly determined by whether or not real interest rates exceed growth rates. If they do (as they tend to in crisis), then the $\bar{g} - r$ term is negative meaning that there is a constant outflow of capital (negative net borrowing) and maintaining the debt level entails a utility loss. In this case a reduction of debt (and hence default) is favorable, because the reduction of debt results in a higher A^D term (negative net borrowing is reduced in absolute value). If real interest rates do not exceed real growth rates (the case in advanced countries most of the time), then maintaining the debt involves positive net borrowing and the government is not interested in lowering the debt level by defaulting.

The main downside to default is the potential endowment decrease when the country descends into a default-triggered crisis. This has probability π_c . The impact depends on the depth (by Assumption 5.2: $g_c = \nu_1 + \nu_2 d(1 - \psi)h$) of the crisis, which determines how much the $\tilde{G}_{Ss,t}$ term is decreased.

Default effects may be even more complicated when taking into account that default may cause exchange rate depreciations and a consequent rise in both debt levels and the external share of debt or changes in the preference for fiscal deficits. Realistically the overall effect on SDV may also depend on how parameters change on the long-run, which is excluded here (parameters return to normal state in the second period). For instance, long-term real interest rate may be affected by default.³² Also trend growth may be affected if there are hysteresis effects. Such long-run effects can be approximated in the model, though, by increasing the length of the short-term period.

5.2 Parametrization

To investigate implications of the model and in particular the effects of fundamental variables on SDV, it is useful to consider plausible ranges and benchmark values for parameters and variables.

Time periods denote one year. As Hatchondo and Martinez (2009), Chatterjee and Eyigungor (2012), Arellano and Ramanarayanan (2012) and others note, having longer-term government debt in the model increases the plausibility of the predictions, whereas modelling one-

³²There is a rationale for a decrease due to the reduced debt ratio, but if reputation effects are relevant as argued by Benczúr and Ilut (2016) for instance, then interest rates may well be higher.

period debt and restricting the period to a quarter has serious shortcomings. I prefer the simplicity of one period bonds and so choose one year maturities that are more realistic (less unrealistic) than quarterly bonds. Choosing the annual frequency also has advantages in terms of presentation and calibration of parameters/variables on low frequency.³³

Table 5.1 outlines the identified ranges for parameters and variables of the model, as well as two base case parametrizations: one for the specification **benchmark**, which aims to identify parameters that follow Aguiar and Gopinath (2006) in most regards. The model in this study, along with that in Arellano (2008), are considered by the detailed literature survey of Stähler (2013) as workhorse models followed by the current quantitative sovereign literature.³⁴

The other specification, named **baseline**, is my own choice of parameters. In contrast to the benchmark parametrization, which is calibrated to data of Argentina, my parameter choices aim to more broadly describe emerging markets and a large group of developed countries. For several variables a historical data set is available, which is used to come up with the baseline values (using the median of observations). There are multiple data sources I use for parametrization as described below. The data sources are described in Appendix A.2.

5.2.1 Benchmark specification

In the benchmark specification trend growth is adjusted to an annual value of 2.4 percent (Aguiar and Gopinath, 2006, use quarterly trend growth of 0.6 percent). The crisis output loss g_C is set to 17 percent.³⁵ The debt ratio is set to a benchmark value of 25 percent, which is roughly the debt ratio supported in that model. Consistent with the paper, which follows the Eaton and Gersovitz (1981) tradition, all debt is assumed to be external ($\psi = 1$). There is no extra value of primary budget deficits ($\alpha_1 = 0$) other than the capital inflow effect on consumption, nor is there a direct externality for choosing default ($\alpha_2 = 0$ on these accounts).

As mentioned before, the benefit of default in the quantitative sovereign models originates from two sources: on one hand, after a default the country benefits from lower debt service if interest rates exceed output growth. On the other hand, after the period of autarky is over, the debt stock is rebuilt, which temporarily increases consumption utility due to capital inflows. This is hard to fit into my framework because debt is constant on the full horizon so here I deviate from Aguiar and Gopinath (2006) and I rather use the logic of Eaton and Gersovitz (1981). In the latter paper the benefit of default is simply the present value of outstanding debt. I use the α_3 parameter, which increases utility by the size of debt relief (debt ratio times the haircut). I set

³³An alternative approach could have been to model longer term bonds as consols in a higher frequency framework as in Hatchondo and Martinez (2009).

³⁴I chose Aguiar and Gopinath (2006) of the two, because Gita Gopinath made her MATLAB code publicly available, so it was fairly easy to recalculate their parametrizations to my settings, e.g. to one-year time periods from quarterly periods.

³⁵This value was calculated as follows. I used the MATLAB code on the website of Gita Gopinath to simulate output paths according to the authors' calibrations. Based on these, I calculated annual growth rates and took the fifth percentile. I opted for the five percent level, because 1-in-20 years recession/crisis are standard industry measures for calculating stress test scenarios.

the parameter to 0.57 (in line with the external debt stock and the assumed 100 percent haircuts in these models and a 2.5 year discount with a 0.8 discount rate).

In [Aguiar and Gopinath \(2006\)](#) the output cost of default is a fixed 2 percent per quarter until the country is excluded from international debt markets (average of 2.5 years). This is incorporated into the benchmark specification by assuming a 100 percent probability for a default-triggered crisis, $\pi_c = 1$, with $T = 2.5$ and $\nu_1 = 0.08$. In the benchmark specification the default cost does not depend on the level of debt, so $\nu_2 = 0$.

The price of bonds are set with (real) interest rates roughly equaling 0.03 or 300 basis points in normal times and 2000 basis points in crisis. These values are chosen to give a rough description of Argentinean real interest rates on foreign currency debt in good and bad times.

I deviate from the paper in assuming a coefficient of relative risk aversion of 1 (log utility) rather than 2 in the paper, which simplifies analytical calculations in this section.

5.2.2 Baseline specification

My baseline specification has several differences compared to the literature benchmark:

- rather than being representative of Argentina it aims to be more broadly representative of emerging and developed countries;
- it allows domestic debt next to external debt;
- it does not impose a full debt writedown;
- the default-triggered utility loss is dependent on the domestic share of debt and the haircut;
- it includes political economy motivated parameters.

The goal of these changes is to describe sovereign credit risk parameters more realistically for a larger set of countries.

Table [5.1](#) summarizes the benchmark and baseline specifications as well as considered parameter ranges.

I will discuss the differences in somewhat more detail here. Where proper data exist, I aimed to choose baseline values around the median and parameter range minima and maxima were intended to be rare but still conceivable values: e.g 5 and 95 percentiles for minima and maxima, which is in line with (business) practice and intuitive calculations of tail risk scenarios. Parameter calibration relies on a large annual historical data set (125 countries, 1970-2010 time period) that I compiled based on various data sets made available by authors on their websites.³⁶

The referenced values below appear in descriptive statistics in Tables [A.9-A.10](#).

³⁶The most important macroeconomic series come from the [Kaminsky, Reinhart and Végh \(2004\)](#) dataset updated with more recent IMF WEO data. Regarding crisis data [Reinhart and Rogoff \(2011b\)](#) and [Laeven and Valencia \(2012\)](#) are my primary sources and additionally [Cruces and Trebesch \(2013\)](#) and [Asonuma and Trebesch \(2016\)](#) for sovereign default related variables. Appendix [A.2](#) describes the historical data set used in more detail.

Under the normal, repayment case baseline trend growth is set to 3.5 percent to roughly match non-crisis period medians (3.8 percent). The lower and higher bounds are set to 0 and 8 percent (trend growth) to approximate the 5 and 95 percentiles (0.3 and 7.8 percent) of the full sample that includes all periods (both normal and crisis periods) and countries.

Reliable estimates for real interest rates are difficult to obtain. The IMF IFS and the data set in [Kaminsky, Reinhart and Végh \(2004\)](#) supplies real treasury bill rates, deposit rates, interbank rates and lending rates, but all of these series are sparse and gross outliers are frequent. Real (domestic) short-term government rates had a median of 2.3 percent in normal periods (more characteristic of advanced countries) and -8.3 to 9.6 percent 5-95 bounds. Emerging market spreads were on average 5 percentage points on foreign exchange debt with 1 and 11 percentage points at the 5 and 95 percentiles since the mid 90s based on EMBI Global data, so in domestic currency this would raise real rates compared to reported real domestic rates in the data set. Developed countries had much smaller spreads until recently. Taken together I chose a baseline value of 3 percent (a definitely benign experience for emerging markets) and bounds are set to -8 and +10 percent.

The debt ratio baseline is set to 50 percent and lower-upper bounds to 10 and 130 percent, close to the median (43 percent) and 5-95 percentiles (9 and 129 percent). External share data come from [Reinhart and Rogoff \(2011a\)](#). In the 1960-2010 period the external debt share for advanced and emerging countries was roughly 10 and 50 percent on average, respectively, and I set the baseline value to 30 percent with bounds 0 and 85 percent near the 5 and 95 percentiles.

The size of the haircut varied widely across debt restructuring episodes (and definitions of haircuts). [Sturzenegger and Zettelmeyer \(2006\)](#) estimate haircuts in the 25 to 70 percent range for episodes between 1995 and 2005 (by the definition of haircut being the share of the bond face value not recovered). However a large share of restructurings had no face value writedowns. [Benjamin and Wright \(2009\)](#) report on average 45 percent haircuts on pre-1995 defaults, a value similar in Brady restructuring experiences ([Andritzky, 2006](#), Table 2.1). With yet another methodology and including episodes from the 1930s [Reinhart and Trebesch \(2016\)](#) estimates debt relief to be 36-43 percent, but claim that this constitutes a lower bound (for the mean estimate). In line with these experiences I set the baseline value for haircuts to 40 percent and use a 5 to 80 percent range.

Turning to political economy parameters, the parameter α_1 that refers to the value of fiscal deficits is set to 0.5 in the baseline specification and its range $[-0.5, 1.5]$ is also tilted towards positive values.³⁷ The political economy parameter of α_2 , which values default over and above

³⁷As mentioned before, there are arguments both in favor of a positive valuation of expansionary fiscal policies (fiscal multipliers larger than 1; political benefits from spending on credit constrained, myopic or impatient households) and against it (empirical studies finds voters not to favor fiscal expansions; expansions theoretically have long-run growth costs). Nevertheless the empirical fact that most countries have significant net government debt instead of net government assets better supports the case for utility of deficits whatever the nature of this utility is. The magnitude of ranges are calibrated with a view on the (unit) effect of external borrowing from which this effect cannot plausibly lie far off and is probably smaller: while external borrowing has a straightforward effect on current consumption the (additional) general fiscal borrowing effect is debatable and depends on challengeable

debt servicing is set to zero, but is allowed to vary between -0.2 and 0.2.³⁸

Estimates on the subjective discount rate are difficult to pin down. Calibrations of sovereign credit risk models customarily use a value of 0.8 (Stähler, 2013). Field experiments by Harrison, Lau and Williams (2002) show significant dispersion among individuals. Some of the dispersion can be attributed to socio-demographic characteristics, but the mean roughly agrees with the value chosen in the sovereign literature. Weitzman (2001) reports much higher discount rates, however, based on a survey of over 2000 economists. Here the median discount rate is around 0.96-0.97 percent. I will use a value 0.9 as the baseline and will consider a wide range of values between 0.5 and 0.99.³⁹

There are several important features of financial crises identified in the literature for the current analysis: (i) they involve large output losses compared to previous trends, (ii) output losses last long: nearly a decade just to reach the pre-crisis real GDP per capita and possibly never returning to the previous trend (Reinhart and Rogoff, 2014), (iii) crises place a significant burden on fiscal budgets (e.g bank recapitalization either replaces other spending, taxes have to be increased or public debt levels increase), (iv) liquidity and credit risk premia raise real interest rates, while a monetary expansion, increasing inflation and a general drive to deleverage acts in the opposite direction, (v) in several cases banking crises are accompanied by a currency crisis, which raises the value of FX debt stocks in domestic currency and acts to deplete international reserves.

Finally, (vi) crises involve large uncertainty about the future economic and financial outlook of the country. This is closely related to the subject matter of the thesis. When crisis hits and economic actors try to figure out how the current crisis is likely to play out (the two key questions of how deep it will be and how long it will last), they find that historical experience and data are usually not relevant in the new context. Compared to the pre-crisis period, the crisis involves structural breaks in relationships between variables that actors became accustomed to. Previous (historical) crisis experiences may not be useful either due to the diversity of crises and the relatively low frequency with which crises are observed. Cross-sectional experience could provide some guidance (experiences of other countries that are currently in crisis and have descended into the crisis just before), and this may provide another justification 'wake-up call' hypothesis besides imperfect information or behavioral biases as discussed in Chapter 4. However, cross-

assumptions in either directions). Calibrating the model in Appendix C.1 with US and EU data in Trabandt and Uhlig (2011) leads to parameters in the range 0.4-0.8. The labor income tax marginal costs in Jonsson and Klein (2003, Table 8) also lead to a similar magnitude, these are estimated to be in the 0.38-0.49 range with three different methods.

³⁸To set plausible ranges for α_2 , it is useful to think of what level of output government (voters) would be willing to sacrifice to be indifferent between default or repayment. The values of ± 0.2 set a utility/disutility of default (of course, added to other costs and benefits specified by other parameters) comparable to the magnitude of a large economic shock (see crisis parameters). Fear of losing integration into the world economy for domestic firms, political reputation costs or more general cultural-societal integration with the advanced world could be relevant factors that add disutility to defaults. At the other extreme, repayment has a disutility for governments/societies belligerent towards lenders.

³⁹The cross-country estimates of Wang, Rieger and Hens (2016) and the cross-study estimates of Frederick, Loewenstein and O'donoghue (2002) show how dispersed these estimates are.

country differences may be even more important, counteracting the relevance of contemporary crisis experiences. Crisis have the points (i)-(v) in common, which differentiates them from normal times, but crisis outcomes are diverse and thus, a priori, there is much uncertainty about shocks to variables and parameters (vi).

I constructed a hypothetical crisis setting here that aims to be both characteristic of broad emerging market and developed country financial crisis experiences and to constitute a meaningful stress scenario for sovereign credit risk. I set the annual output loss to 6 percent of real GDP (loss compared to endowment trend), which is somewhat smaller than the median of 6.9 of crisis cases reported in [Laeven and Valencia \(2018\)](#) (see Appendix Table A.11). The rationale for this correction is accounting for the effect of truncation of crisis duration at 5 years, which is likely to upwardly bias the mean of annual output losses, because when real crisis length is longer crisis-ends are likely to feature smaller losses than the first 5 years.⁴⁰ The bounds for losses are set to 0.01 and 25 percent again mildly dampened compared to the empirical percentiles (0 and 32.4 percent) in the data provided by these authors. The initial crisis probability is set to 0.05 as in the benchmark case and a range of 0.01 to 1 is considered.

The distribution of real interest rates tends to be much more dispersed in financial and sovereign crises based on the [Kaminsky, Reinhart and Végh \(2004\)](#) data set. Median real interest rates in crises are similar to the non-crisis sample. However, since real rates are calculated with ex post inflation data, the economically more meaningful ex ante rates are likely to be higher in crisis periods, because crises often exhibit inflation surprises. To constitute a stress scenario, I chose a value of 7 percent (4 percentage points above normal baseline). Medians mask a very large dispersion of real interest rates: -30 to 12 percent 5-95 percentiles on financial crisis samples. I use parameter bounds of -15 and +15 percent.

Crisis length is set to a baseline value of 4 years, which is longer than the [Laeven and Valencia \(2018\)](#) data set median of 3 years to compensate for the truncation in this data set at 5 years. The chosen baseline value is still shorter than the average reported in [Reinhart and Rogoff \(2014\)](#) (see previous footnote). To account for the large uncertainty around crisis duration ranges considered are 1 to 100 years (the latter effectively denoting hysteresis effects of the crisis).

⁴⁰Two points are worth noting. First, there is considerable heterogeneity of reported crisis effects in the literature. This originates from different samples as well as different definitions of losses. [Reinhart and Rogoff \(2014\)](#) calculate with real GDP per capita levels (not deviations from trend), but the data I use based on [Kaminsky, Reinhart and Végh \(2004\)](#) has trend growth rates, which also adjust downwards during crises. More consistent with my model are [Laeven and Valencia \(2018\)](#), [Fatas and Mihov \(2013\)](#) and [Romer and Romer \(2017a\)](#), which report deviations from previous trends although calculation of trend is different in each. Of the three [Laeven and Valencia \(2018\)](#) works on a significantly larger data set than the other two studies, which explains my choice. Second, in my model the level of real output compared to trend is reduced in the first period and the deviation (in percentage terms) remains constant during the crisis. In reality the dynamics are smoother, growth declines gradually towards its peak loss at around 2-3 years after initiation of the crisis and slowly recovers thereafter ([Fatas and Mihov, 2013](#); [Reinhart and Rogoff, 2014](#); [Romer and Romer, 2017a](#)). According to [Reinhart and Rogoff \(2014, Table 2 p. 54\)](#) real GDP recovers to pre-crisis levels in 7-8 years on average. The coarse real dynamics in my specification upwardly biases estimates of output losses somewhat due to the effect of discounting, although this again depends on definitions of the start of the crisis. To compensate for the upward bias due to the instantaneous rather than gradual output adjustment, I use a shorter, 4 year average length for the crisis, which is longer than the median 3-year crisis duration in [Laeven and Valencia \(2018\)](#) as discussed above.

Based on [Laeven and Valencia \(2012\)](#) systemic banking crises also had large fiscal costs and resulted in increased public debt ratios. In the historical data set as well, debt ratios tend to be higher in financial crises, and the higher end of the distribution shifts up markedly especially in sovereign crises signalling significant potential upsides. The model assumption of fixed debt to trend output leads to a temporary increase in debt ratios in crisis, because output in these spells drops below trend. However, other explicit increases in debt (or its external component) are not considered here, but are considered in the quantitative model of [Appendix C.2](#).

The effect on subjective discount rates and risk aversion in crisis is ambiguous. Appealing to prospect theory and loss aversion would increase risk seeking, whereas ambiguity aversion would probably increase the CRRA parameter in the model. Similarly, political economy parameters may be argued to either increase or decrease. These parameters are left at their normal baseline value for the crisis.

Table 5.1: Parameter ranges and base case values

Parameter/Variable	Specification values		Parameter Ranges	
	Benchmark	Baseline	Minimum	Maximum
$\bar{g}$	0.02	0.04	0.00	0.08
π_C	0.05	0.05	0.01	1.00
g_C	0.17	0.06	0.01	0.25
r	0.03	0.03	-0.08	0.10
r_C	0.20	0.07	-0.15	0.15
d	0.25	0.50	0.10	1.30
ψ	1.00	0.30	0.00	0.85
h	1.00	0.40	0.05	0.80
α_1	0.00	0.50	-0.50	1.50
α_2	0.00	0.00	-0.20	0.20
α_3	0.57	0.00	0.00	1.00
π_c	1.00	0.30	0.01	1.00
ν_1	0.08	0.06	0.00	0.25
ν_2	0.00	0.15	0.00	0.25
β	0.80	0.90	0.50	0.99
T	2.50	4.00	1.00	100.00

Sources: author's compilation.

Notes: The table shows parametrization for two model settings: Benchmark (based on literature) and Baseline (developed here, where available: close to medians of proxies on a historical data set); and parameter ranges that cover their plausible domain: the extrema are intended to be still conceivable, though rarely occurring values (where available: close to 5-95 empirical percentiles).

The default-triggered crisis parameters are set as follows. Crisis occurs in sovereign default with only 30 percent probability.⁴¹ The range allowed for this parameter spans 0.01 to 1 to account for large uncertainty.

⁴¹This is much larger than the small empirical coincidence of sovereign defaults and other crisis found by [Laeven and Valencia \(2012\)](#). However, as argued before, these empirical findings are subject to selection bias: those governments, where default has a larger perceived probability of triggering crisis are more likely to do everything in their means to evade a default. Sovereign defaults have largely evaded developed countries, where the domestic bond market is larger and defaults more likely lead to a credit crunch ([Gennaioli, Martin and Rossi, 2014](#)).

The unconditional crisis depth parameter, ν_1 , is set to a similar magnitude as the non-default induced crisis (baseline 6 percent and range of 0 to 25 percent).

The parameter ν_2 adds output loss due to financial strains in the country. More precisely, it accounts for the sensitivity of output loss due to bank losses on domestically held government securities. [Reinhart and Rogoff \(2011a\)](#) documents that domestic sovereign debt crises are associated with larger output losses than external debt crises. [Romer and Romer \(2017b\)](#) finds that output losses are larger when there is a larger overhang of debt outstanding in a financial crisis. Also the [Laeven and Valencia \(2018\)](#) data set supports a weak positive correlation between the size of output losses and various proxies for financial strains in systemic banking crises (see Appendix Table A.11 10.2.2).

Unfortunately, there are no empirical studies, which directly estimate the output effects of such bond valuation losses, so parametrization is necessarily ad hoc. I set the baseline value for ν_2 to 0.15, which adds 2 percent annual output loss at baseline parameter settings of d , ψ and h . To account for the large uncertainty regarding this parameter, I consider the wide ranges of 0-0.25. The minimum represents no effect of bond losses to banks on output, whereas at the maximum with maximum domestic bondholdings and haircut annual output loss is 25 percent, a similar magnitude as the maximum of ν_1 .

5.2.3 SDV in benchmark and baseline specifications

Table 5.2 compares SDV of benchmark and baseline specifications. Based on the upper panel both the benchmark and baseline specifications predict repayment in normal times ($S = N$) as SDV is below 0, -0.024 and -0.101 respectively. However, sovereign default is predicted in crisis ($S = C$) for the benchmark specification ($SDV = 0.03$). In the baseline setting the crisis increases SDV by 0.024 to -0.076, but this is still far from the positive (default) territory. On one hand, the difference between the two settings is due to the benchmark being calibrated to more severe Argentinean crisis experiences (e.g a 17 percent output loss vs 6 percent in the baseline; 2000 basis points real interest rates in the benchmark vs 700 in the baseline). On the other hand, it is due to several simplifications in the benchmark setting compared to the baseline (e.g the benchmark assumes full debt writedowns and no domestic debt).

The state labeled as basic in the table mixes the normal and crisis states and can be thought of taking an expectation of SDV prior to knowledge of the state of nature. The basic state gives a 95 percent weight to the normal state (in line with the crisis scenario being a 1-in-20 years event) and due to this large weight, there is no default predicted in the basic state for either the benchmark or the baseline.

The bottom panel seeks to explain what factors explain the baseline SDV (-0.100) being about 0.08 points lower than that of the benchmark (-0.022). The procedure I follow is to evaluate the benchmark and baseline scenarios with parameters swapped between the two.

When swapping growth variables, the benchmark SDV decreases by 0.01 points to -0.032

Table 5.2: Comparing SDV of benchmark and baseline specifications

setting/altered parameters	description	SDV		SDV - SDV _{basic}		rationale
		benchmark	baseline	benchmark	baseline	
nature: normal	set $\pi_C = 0$	-0.024	-0.101	-0.003	-0.001	in normal times, there is no default (baseline SDV lower) .. SDV positive in benchmark (predicts default), not in baseline
nature: crisis	set $\pi_C = 1$	0.030	-0.076	0.052	0.024	
basic	set $\pi_C = 0.05$	-0.022	-0.100	0.000	0.000	
growth effect	swap $\bar{g}, g_C$	-0.032	-0.085	-0.010	0.015	baseline SDV increases with lower growth rates ...
real interest rate effect	swap r, r_C	-0.025	-0.123	-0.003	-0.023	... and decreases with higher interest rates specified in benchmark
debt ratio effect	swap d	0.133	-0.081	0.154	0.019	opposite effects: baseline SDV up, as lower debt decreases default costs
external rate effect	swap ψ	-0.129	-0.091	-0.108	0.009	lower external rate decreases default benefits in bmk,
haircut effect	swap h	-0.160	-0.135	-0.139	-0.035	minor role in baseline opposite effects: baseline SDV down as higher haircut increases default costs
default crisis effects	swap ν_1, ν_2, π_c	0.115	-0.315	0.137	-0.215	default-crisis costs larger in benchmark, would reduce baseline SDV
default benefits effects	swap $\alpha_1, \alpha_2, \alpha_3$	-0.158	-0.056	-0.137	0.044	default benefits larger in benchmark, would increase baseline SDV
patience, crisis length effect	swap β, T	-0.119	-0.061	-0.097	0.039	high impatience in benchmark increases default benefits

Sources: author's compilation.

Notes: The table shows SDV (strategic default value) for the benchmark and baseline parametrization under different scenario settings (rows). The upper part of the table shows SDV values for normal/crisis states of nature and a setting labelled basic that mixes these two states shares 95 to 5. Departing from this basic setting, the bottom panel investigates the sources of SDV differences between the benchmark and baseline parametrization. To do so, it shows how SDV would change, were various parameters swapped between the benchmark and baseline sets. The first two columns describe the scenario settings, the second two display SDV (recall: positive values denote the choice to default), the next two compare SDV to basic SDV, the last column provides some narrative.

and the baseline SDV increases by 0.015 points to -0.085. This is because of lower benchmark (Argentina) growth rates (both the trend and the crisis gap). Incorporating a higher growth rates into the benchmark scenario decreases the motivation to default in this setting, which lowers SDV, whereas a more adverse growth incorporated into the baseline scenario has the opposite effect and increases SDV.

Swapping the real interest rate has nearly no effect on SDV in the benchmark case, but it decreases the value of defaulting in the baseline by 0.02. In the model, a default potentially triggers a crisis with high interest rates when $S = N$ and $s = c$, and since crisis rates are significantly larger in the benchmark parameter setting, this reduces expectations for utility when choosing a default, which reduces SDV.

The debt ratio is lower in the benchmark scenario (0.25) than in the baseline (0.5). Within the benchmark specification receiving a higher debt ratio (from the baseline) increases SDV, the relative value of default. This is a straightforward implication of models in the sovereign literature. In the [Aguilar and Gopinath \(2006\)](#) study roughly 0.2-0.3 debt ratios are supported (i.e. are the maximum that still predict repayment), so the 0.5 debt ratio would be consistent with a default in that calibration. However, in the baseline setting a lower debt ratio (swapped from the benchmark) increases SDV rather than reducing it, which contrasts other models. This is due to two factors. On one hand, a lower (domestic) debt reduces the costs of a default, because it reduces effects of a potential default-triggered domestic crisis. On the other hand, the basic setting inherits the normal scenario property of $\bar{g} > r$. Together with $\alpha_1 + \psi > 1$ (an assumption likely to hold in most cases) this implies higher net borrowing being associated with maintaining a higher debt ratio. Thus a higher debt ratio (and thus repayment) is utility enhancing. Of course, this result hinges on both the assumption of an exogenously given interest rate that is independent of d and fixed debt levels.

A higher external debt share ψ increases the motivation to default in the benchmark scenario and slightly also increases SDV in the baseline. Therefore the benchmark SDV decreases with a swapped, smaller external debt and the baseline SDV marginally increases with the higher external debt. The overall effect of ψ in the baseline scenario is the sum of a negative effect due to net borrowing (higher external share of debt increases utility gains from net borrowing and so the status quo of repayment is preferred more) and a positive effect due to a default-triggered crisis (when debt shifts from domestic to external, the cost of default decreases, which increases SDV).

Changing the haircut has opposite effects in the two scenarios. Lowering the haircut to the baseline level decreases default benefits and thus decreases SDV in the benchmark case. In the baseline setting a higher haircut has the same effects mentioned above for the debt ratio: it increases costs of a potential domestic financial crisis triggered by default, and it reduces the debt level at a time when maintaining higher debt is favorable.

The effects of swapping default-triggered crisis parameters are more substantial in both settings. The benchmark setting has a more severe output loss primarily because it assumes a 100 percent incidence of crisis (autarky). Thus using the baseline crisis losses increases the benchmark SDV, because the output costs of a default decline. Similarly, the increased default cost of the benchmark setting makes default a substantially worse option for the baseline scenario.

Swapping the α parameters has effects that follow from larger benefits of default in the benchmark case (full debt relief, assuming that default benefit is the debt value itself). Including the milder benefits of the baseline lowers benchmark SDV, whereas benchmark parameters would increase SDV for the baseline setting.

The β and T parameters act in the same direction. Crisis length are similar in the two cases, but time discount is significantly lower in the benchmark. Less impatient consumers would lead the government to give more value for repayment in the benchmark case. In the baseline setting

more impatience would increase SDV.

In sum, the key differences between the two specifications are the following: (i) real growth rates are more adverse in the benchmark case, which increases the value of default relative to the baseline; (ii) default output losses may be deeper in the baseline case, but are assumed to have a lower probability of occurring, which increases SDV in the baseline relative to the benchmark. (iii) Higher crisis interest rates decrease the value of default in the baseline, but not in the benchmark; (iv) SDV is increasing in debt ratio and haircut in the benchmark, but decreasing in the baseline case. The baseline case has default costs increasing in these parameters, because default may trigger a domestic financial crisis. Also: in times, when trend growth exceeds real interest rates higher debt levels are favored in the baseline scenario, which motivates the government to stay in the contract and keep debt high.

5.3 Fundamental effects on SDV

In this section I turn to derivations of how fundamentals affect SDV and hence the sovereign credit risk. This will allow later discussion of how the relationship between fundamentals and sovereign risk can vary over time.

It is useful to explicitly note at this point the link between fundamentals, SDV and the risk of default.

SDV is calculated as a difference between the payoffs (value functions) in default and repayment. SDV in turn is determined by fundamentals, because these have an effect on utility through value functions. Since SDV is directly linked to the default decision (default occurs when SDV is positive) fundamentals have an effect on the default decision through SDV.⁴²

The model so far grasps the effects of the following country fundamentals:

- Real trend growth rate is captured by $\bar{g}$.
- The cyclical position of the real endowment is proxied by g_C . Although it is used here as the initial crisis state output loss, it can be understood more generally as a cyclical position indicator. The output loss in a default-triggered crisis is ν_1 and the domestic debt dependent variable $\nu_2 d(1 - \psi)h$. The parameters π_C and π_c control the probabilities of crises.
- Real interest rates r and r_C given as fixed, but state dependent quantities.
- The (structural) government debt ratio, d .

⁴²The effect of fundamentals on SDV is, naturally, not the same as the effect on the default decision as SDV is continuous, whereas the default decision is binary. However the effect on SDV does relate to the effect on default risk. This is easiest to see, when the level of SDV is considered to be uncertain. A fundamental that has large effect on SDV has a larger potential to tip SDV into default territory even when SDV is significantly negative. A fundamental that has slight impact on SDV, may only be relevant in the default decision if SDV is very close to 0. In that case the value of the given fundamental can mean the difference between repayment and default.

- The primary (structural) fiscal balance (net borrowing), which is determined by trend growth, real interest rates and the debt ratio.
- The current account balance (net foreign borrowing) is limited to public sector flows and is determined by the fiscal balance and ψ .
- The external debt stock is given by ψd (only public sector balance sheets are captured).
- Considerations about the value of fiscal prudence, net borrowing and debt service is captured by the parameter α_1 .
- The political economy stance toward debt repayment is captured by α_2 , which depends on government views about economic and political integration with the outside world (regarding external debt), redistribution between domestic investors and taxpayers, and embracing of property rights, rule of law and market institutions: in general how market friendly the political-institutional framework is.⁴³
- The β parameter controls time preference, which may also be linked to country fundamentals.

The effects of fundamentals (denote generally by Z) on the government willingness to pay is reflected by the derivative of SDV with respect to Z .

Based on equation (5.7) this derivative has an additive structure (ignoring the trivial case of $Z = \alpha_2$), a probability-weighted sum of the short-term initial normal and crisis SDV derivatives and the long-term SDV derivative, which is independent of the initial state.

$$\frac{\partial SDV}{\partial Z} = (1 - \pi_C) \frac{\partial SDV_N^{(1)}}{\partial Z} + \pi_C \frac{\partial SDV_C^{(1)}}{\partial Z} + \frac{\partial SDV^{(2)}}{\partial Z}, \quad (5.8)$$

These components are each differences of the relevant default and repayment derivatives in each of these states. Due to logarithmic utilities, the derivatives themselves are the partial derivatives of the relevant A terms divided by the A terms.

$$\begin{aligned} \frac{\partial SDV_N^{(1)}}{\partial Z} &= \frac{1 - \beta^T}{1 - \beta} \left((1 - \pi_c) \frac{\partial A_{Nn}^{(1)D} / \partial Z}{A_{Nn}^{(1)D}} + \pi_c \frac{\partial A_{Nc}^{(1)D} / \partial Z}{A_{Nc}^{(1)D}} - \frac{\partial A_{Nn}^{(1)R} / \partial Z}{A_{Nn}^{(1)R}} \right), \\ \frac{\partial SDV_C^{(1)}}{\partial Z} &= \frac{1 - \beta^T}{1 - \beta} \left((1 - \pi_c) \frac{\partial A_{Cn}^{(1)D} / \partial Z}{A_{Cn}^{(1)D}} + \pi_c \frac{\partial A_{Cc}^{(1)D} / \partial Z}{A_{Cc}^{(1)D}} - \frac{\partial A_{Cn}^{(1)R} / \partial Z}{A_{Cn}^{(1)R}} \right), \\ \frac{\partial SDV^{(2)}}{\partial Z} &= \frac{\beta^T}{1 - \beta} \left(\frac{\partial A^{(2)D} / \partial Z}{A^{(2)D}} - \frac{\partial A^{(2)R} / \partial Z}{A^{(2)R}} \right). \end{aligned} \quad (5.9)$$

Recall that A terms are specified as:

⁴³This could be thought of both as a general mentality of politicians and society or as rational calculation of the benefit of being market-friendly: Baldacci, Gupta and Mati (2008) considers a political capital concept, Cole and Kehoe (1998) considers general reputations and economic externalities of a default.

$$A_{Ss,t}^{R/D} = \tilde{G}_{Ss,t} + d(1 - h\lambda^g) \frac{(\psi + \alpha_1)(\bar{g} - r_{Ss,t})}{(1 + \bar{g})(1 + r_{Ss,t})},$$

where $\tilde{G}_{Ss,t}$ denotes the output gap compared to trend output. The default A terms (A^D) have a debt ratio reduced by hd compared to the repayment policy (A^R). Crisis (initial or default-triggered) on the other hand reduces G and increases r .

Table 5.3 summarizes the components for several fundamentals (rows) for given states of nature and government choice (columns and upper/lower panels).

Table 5.3: Components of fundamental effects on SDV

PANEL A: Normal State $S = N$			
Repay/Default	R	D	D
Default-crisis	n	n	c
G_{Ss}	$G_N = 1$	$G_N = 1$	$G_c = (1 + \bar{g} - g_c)/(1 + \bar{g})$
R_S	$R_N = (\bar{g} - r)/(1 + r)$	$R_N = (\bar{g} - r)/(1 + r)$	$R_C = (\bar{g} - r_C)/(1 + r_C)$
$(1 - h\lambda)d$	d	dH	dH
P	$(\psi + \alpha_1)/(1 + \bar{g})$	$(\psi + \alpha_1)/(1 + \bar{g})$	$(\psi + \alpha_1)/(1 + \bar{g})$
A	$G_N + dPR_N$	$G_N + dHPR_N$	$G_c + dHPR_C$
$\partial A/\partial d$	$\frac{\partial G_{Ss}}{\partial d} + PR_N$	$\frac{\partial G_{Ss}}{\partial d} + HPR_N$	$\frac{\partial G_{Ss}}{\partial d} + HPR_C$
$\partial G_{Ss}/\partial d$	0	0	$-\nu_2 h(1 - \psi)/(1 + \bar{g})$
$\partial A/\partial r$	$dP \frac{\partial R_N}{\partial r}$	$dHP \frac{\partial R_N}{\partial r}$	$dHP \frac{\partial R_C}{\partial r}$
$\partial R/\partial r$	$-(1 + \bar{g})/(1 + r)^2$	$-(1 + \bar{g})/(1 + r)^2$	$-(1 + \bar{g})/(1 + r_C)^2$
$\partial A/\partial g_c$	0	0	0
$\partial A/\partial \bar{g}$	$\frac{\partial G_{Ss}}{\partial \bar{g}} + dP \frac{\partial R_S}{\partial \bar{g}}$	$\frac{\partial G_{Ss}}{\partial \bar{g}} + dPH \frac{\partial R_S}{\partial \bar{g}}$	$\frac{\partial G_{Ss}}{\partial \bar{g}} + dPH \frac{\partial R_C}{\partial \bar{g}}$
$\partial G_{Ss}/\partial \bar{g}$	0	0	$g_c/(1 + \bar{g})^2$
$\partial R_S/\partial \bar{g}$	$1/(1+r)$	$1/(1+r)$	$1/(1 + r_C)$
PANEL B: Crisis State $S = C$			
Repay/Default	R	D	D
Default-crisis	n	n	c
G_{Ss}	$G_C = (1 + \bar{g} - g_C)/(1 + \bar{g})$	$G_C = (1 + \bar{g} - g_C)/(1 + \bar{g})$	$G_{Cc} = (1 + \bar{g} - g_C - g_c)/(1 + \bar{g})$
R_S	$R_C = (\bar{g} - r_C)/(1 + r_C)$	$R_C = (\bar{g} - r_C)/(1 + r_C)$	$R_C = (\bar{g} - r_C)/(1 + r_C)$
$(1 - h\lambda)d$	d	dH	dH
P	$(\psi + \alpha_1)/(1 + \bar{g})$	$(\psi + \alpha_1)/(1 + \bar{g})$	$(\psi + \alpha_1)/(1 + \bar{g})$
A	$G_C + dPR_C$	$G_C + dHPR_C$	$G_{Cc} + dHPR_C$
$\partial A/\partial d$	$\frac{\partial G_{Ss}}{\partial d} + PR_C$	$\frac{\partial G_{Ss}}{\partial d} + HPR_C$	$\frac{\partial G_{Ss}}{\partial d} + HPR_C$
$\partial G_{Ss}/\partial d$	0	0	$-\nu_2 h(1 - \psi)/(1 + \bar{g})$
$\partial A/\partial r_C$	$dP \frac{\partial R_C}{\partial r_C}$	$dHP \frac{\partial R_C}{\partial r_C}$	$dHP \frac{\partial R_C}{\partial r_C}$
$\partial R_C/\partial r_C$	$-(1 + \bar{g})/(1 + r_C)^2$	$-(1 + \bar{g})/(1 + r_C)^2$	$-(1 + \bar{g})/(1 + r_C)^2$
$\partial A/\partial g_c$	$-1/(1 + \bar{g})$	$-1/(1 + \bar{g})$	$-1/(1 + \bar{g})$
$\partial A/\partial \bar{g}$	$\frac{\partial G_{Ss}}{\partial \bar{g}} + dP \frac{\partial R_S}{\partial \bar{g}}$	$\frac{\partial G_{Ss}}{\partial \bar{g}} + dPH \frac{\partial R_S}{\partial \bar{g}}$	$\frac{\partial G_{Ss}}{\partial \bar{g}} + dPH \frac{\partial R_S}{\partial \bar{g}}$
$\partial G_{Ss}/\partial \bar{g}$	$g_C/(1 + \bar{g})^2$	$g_C/(1 + \bar{g})^2$	$(g_C + g_c)/(1 + \bar{g})^2$
$\partial R_S/\partial \bar{g}$	$1/(1 + r_C)$	$1/(1 + r_C)$	$1/(1 + r_C)$

Sources: author's compilation.

Notes: The table shows components of the effect of fundamentals on SDV (strategic default value). The two panels are divided by initial nature state N, C . Columns represent government choice R, D and states of nature conditional on default n, c . SDV components are in each state $G_{Ss} + (1 - h\lambda)d \frac{\psi + \alpha_1}{1 + \bar{g}} \frac{\bar{g} - r_S}{1 + r_S}$ and $P = (\psi + \alpha_1)/(1 + \bar{g})$, $R_S = (\bar{g} - r_S)/(1 + r_S)$, $H = (1 - h)$ serve to simplify presentation of this expression.

The structure and components of the derivative of the strategic default value already suggest some intuition about how fundamentals affect the willingness to repay. On one hand, (due to logarithmic utility and risk aversion, more generally) all the above listed fundamental variables are part of the A terms, which are the denominators of $\partial SDV/\partial Z$ in equation (5.9). This suggests that the effect of fundamentals on SDV depend on the levels of other fundamental

variables, so variable interactions may be important. Also, and related to this point, fundamental effects also depend on the level of the fundamental with respect to which the derivative of SDV is taken. This suggests that effects on SDV may be non-linear.

Another potential source of non-linearity in fundamental effect is the initial state of nature. Fundamentals may affect the government default decision differently under the normal and crisis states, because the two involve different endowment levels and real interest rates. If these latter factors are important in modifying other fundamental effects then different realizations of initial states of nature also causes regime shifts in fundamental effects.

5.3.1 Sign of effects (analytical results)

Except for the simple case of α_2 , which has a unit (positive) effect on strategic default value, other fundamental parameters have a less straightforward effect on SDV and in most cases even the signs are dependent on the value of other fundamentals.

This contrasts some mainstream results in the literature, where the motivation to default are monotonous functions of fundamentals. Notably, a standard result of other models in the theoretical literature is a positive relationship between the debt level and credit risk⁴⁴. A less uniform, but usual result is that the increase in the real endowment reduces credit risk.⁴⁵

The following propositions provide sufficient conditions for monotonicity of fundamental effects on SDV. In the case of several parameters I show that there are sufficient conditions (within allowed parameter ranges) for both signs of effect, i.e that the effect of the parameter is ambiguous. I do not aim to describe signs of effects for the full allowed parameter space.

Proposition 5.1. *(Effect of trend growth)*

Assume $r = r_C$ and $0 < \psi + \alpha_1$.⁴⁶ Then SDV is decreasing in $\bar{g}$.

Proof. Appendix B.1. □

The intuition for the result is best understood from equation (5.3). Although trend growth also discounts $\tilde{G}_{S,t}$ and appears in the denominator of the right-hand (net borrowing) term, it has its main impact on SDV through (positively) influencing the nominator of the right-hand (net borrowing) term. When net borrowing is valued positively by the terms $(\psi + \alpha_1)$ as is

⁴⁴Prominent examples of statements that credit risk increases with debt (or debt servicing or inverse of government net assets) are Eaton and Gersovitz (1981, Theorem 1, p.291), Aguiar and Gopinath (2006, p.73) and Arellano (2008, Proposition 1, p.697)

⁴⁵This result is conditionally true in standard models. For example, Eaton and Gersovitz (1981, Proposition 5, p.298) claims the ambiguity of this relationship. The intuition is that as the growth rate increases, both borrowing capacity and desired borrowing increases with opposing effects. Which effect is stronger depends on other parameters. In the model of Arellano, however, the relationship is shown to be negative (Arellano, 2008, Proposition 3, p.698).

⁴⁶The assumptions $r = r_C$ and $0 < \psi + \alpha_1$ are used in several propositions to simplify derivations. Note however, that $0 < \psi + \alpha_1$ takes up most of the range that this sum can take: $[-0.4, 2.4]$ by parameter bound assumptions. The assumptions $r = r_C$ is restrictive only if there is a large difference between crisis and non-crisis rates. On historical data both non-crisis and crisis real interest rates are very dispersed but their medians are close: nominal interest rates tend to increase in crises, but so does inflation.

supposed to be in most cases (unless debt is nearly fully domestic and there is a value on fiscal prudence) then trend growth has a positive value that increases with debt, because it enables the government to borrow more without increasing the (structural) debt ratio. Sovereign default reduces the debt ratio and, through it, net borrowing relative to the repayment policy. Of course this hinges on the assumption of expectation of constant debt ratios, i.e. that government does not calculate with opportunistically running up debt again in the future. The rationale for this assumption was discussed in Section 5.1. The sign of effect may switch to positive only in cases of extremely large and long-lasting default-triggered crises, in which case increasing trend growth may reduce negative effects of the default output loss through the $\tilde{G}_{ss,t}$ term. However, under plausible parameter values trend growth has a robust negative effect on the willingness to default.

Proposition 5.2. *(Effect of initial crisis output loss)*

The sign of the effect g_C on SDV depends on other fundamentals.

If $g_c \leq h(\psi + \alpha_1)(r_C - \bar{g})/(1 + r_C)$ then SDV is increasing in g_C .

If $\nu_2 = 0$ and $0 < \psi + \alpha_1, \bar{g}, r < r_C$, then SDV monotonically decreases in g_C .

Proof. Appendix B.1. □

Crisis output loss that is not due to default but the initial state of nature, g_C , reduces output by a similar magnitude whether or not government chooses repayment or default. The difference in the valuation of such an output loss is due to two factors. A default may induce both a higher or lower utility level (A terms in equation 5.9) and since this enters SDV partial derivatives due to risk aversion (log utility) a larger crisis may either increase or decrease the willingness to repay. Whether SDV is increased or reduced in a crisis depends on several factors and these are what the assumptions in the proposition distinguish.

Simulations reveal (see Figure 5.3 below) that non-default crisis output losses only have a minor effect on SDV. The curvature of utility due to risk aversion and the crisis loss magnitudes are small to be of too much importance relative to other variables. Again, model assumptions are important here, notably that governments aim to keep the *structural* debt ratio constant, which results in countercyclicality. If governments are inclined to deleverage in crisis and then (non-default) crisis could have a more significant effect on SDV. The historical annual data set presented in the appendix reveals that debt ratios tend to increase rather than decrease in crises, although the distribution of changes is large. A sudden stop could reduce or reverse new net borrowing from abroad, but higher interest payments, profit repatriation and valuations (exchange rate depreciation), as well as realized conditional liabilities (for instance, bank bailouts) could counteract the effect in the current account and could result in increasing foreign liabilities.

The result is similar to Aguiar and Gopinath (2006) in that transitory income fluctuations have a smaller effect than trend growth on the difference between the default and repayment states ($\hat{V}_B - \hat{V}_G$ is the notation of that study, which is equivalent to SDV here). In that model, too, when a positive and persistent endowment shock is realized, then repayment capacity increases,

because growth (and the value of net borrowing) exceeds debt service (interest on the prevailing debt level) on the longer run. This allows higher supported debt ratios. In contrast, transitory and short-term fluctuations do not materially change the relative value of repayment, because future endowments and thus repayment capacity are not affected by the current shock.

Proposition 5.3. *(Effect of default-triggered crisis output loss)*

SDV is a decreasing function of ν_1 and ν_2 parameters.

Proof. Appendix B.1. □

The intuition of the proposition is straightforward from Assumption 5.2, which specifies the structure of output losses in default. Important to note is that the effect of ν_2 increases in the size of domestic debt and the haircut. The magnitude of both ν_1 and ν_2 parameter effects are also dependent on the length and relative importance of the crisis state and hence parameters π_c , T , β . Altogether this highlights the potential for variable interactions to be important here, an issue I turn to below.

Proposition 5.4. *(Effect of crisis duration)*

The sign of the effect depends on other parameters.

Assume $r = r_C$.

If the initial crisis state SDV component exceeds the long-term state SDV component and $g_c = 0$, then SDV is an increasing function of T .

In contrast, if $\pi_C = 0$ and $0 < g_c$, then SDV is a decreasing function of T .

Proof. Appendix B.1. □

The parameter T is an expectation of crisis-length for both default-triggered and initial crises. This causes the ambiguity of its effect on SDV. Intuitively, when the initial crisis is such that government is more motivated to default relative to the normal state and default-triggered crisis is less relevant, then longer crisis duration increases the strategic default value.

On the other hand, if the initial crisis state has a low probability of occurring and defaults are associated with meaningful endowment losses, then longer crisis duration reduces the value of strategic default.

Proposition 5.5. *(Effect of time preference)*

SDV is a decreasing function of β if $0 \leq g_c$, $r = r_C$ and there is repayment in the long-term state.

Proof. Appendix B.1. □

Numerical simulations show that the effect of β on SDV is negative outside of some extreme parameter settings. The proposition provides conditions when SDV is certain to decrease as β increases. The general intuition is that as β increases, i.e. as the government (voters) become more patient, the long-term becomes more important than the short-term. Also, the endowment

loss in a default reduces SDV by a term $(1 - \beta^T)/(1 - \beta)$ (see equation B.1) and this disutility term becomes larger with β in given β and T parameter ranges. (Note the difference with respect to T , which would decrease this term.) Therefore this factor also contributes to the negative effect of β on SDV.

Proposition 5.6. *(Effect of real interest rates)*

Assume $r = r_C$ and $0 < \psi + \alpha_1$. If $g_c/(1 + \bar{g}) \leq h$, then SDV increases in r .

Proof. Appendix B.1. □

Intuitively, a default reduces outstanding debt so that an increase in real interest rate has a positive effect on utility if net capital outflows (debt servicing) are valued negatively ($0 < \psi + \alpha_1$). The magnitude of the effect depends positively on several parameters: ψ , α_1 , d and h .

Proposition 5.7. *(Effect of the debt ratio)*

The sign of the effect of d on SDV is ambiguous.

Assume $r = r_C$ and $0 < \psi + \alpha_1$.

SDV is an increasing function of d if $\bar{g} \leq r$ and $\pi_c = 0$.

SDV is a decreasing function of d if $0 \leq \pi_c, \nu_2$ and $r = r_C \leq \bar{g}$.

Proof. Appendix B.1. □

There are two forces that compete in determining how d effects SDV. The value of default relative to repayment is reduced as (domestic) debt increases due to the reduced endowment when default triggers a crisis. This negative effect may, however, be offset by a reduction of debt if it implies a large enough increase in future net borrowing (decrease of capital outflow due to debt service).

With $r < \bar{g}$ (and assuming that net borrowing positively affects current utility, i.e. $0 < \psi + \alpha_1$) the latter positive effect is not possible, because reduction of debt in a default reduces net borrowing and hence utility. In this case SDV is decreasing in d . When $\bar{g} < r$ and the negative effect of the default crisis is small, then SDV may be increasing in d .

Note that the magnitude of the effect depends on several parameters in this model. For instance, the importance of a default-triggered crisis is determined by its probability π_c , the output loss independent of domestic debt (ν_1) and parameters determining the depth of the domestic debt-dependent part of crisis ($\nu_2, 1 - \psi, h$). Also crisis duration and patience (β, T) matter. The utility gained from a reduction of debt depends on $\bar{g} - r, \psi, \alpha_1, h$. So variable interactions are likely to be important.

Proposition 5.8. *(Effect of external debt share)*

The sign of the effect of ψ on SDV is ambiguous.

Assume $r = r_C$ and $0 < \psi + \alpha_1$.

SDV is an increasing function of ψ if $\bar{g} \leq r = r_C$.

SDV is a decreasing function of ψ if $\nu_2 = 0$ and $r = r_C \leq \bar{g}$.

Proof. Appendix B.1. □

The effect of ψ also depends on the role of a default-triggered crisis and how net borrowing is valued. A higher ψ (less domestic debt) reduces the endowment loss in a default and hence raises SDV. It also increases the absolute value of net borrowing valuation, but the sign here depends on $\bar{g} - r$. A combination of low real rates relative to trend growth and small perceived crisis costs leads to SDV decreasing in ψ , however high crisis costs instead tend to increase the willingness to default. The magnitude depends again on nearly all other parameters, notably all those influencing the effect of d with the exception of α_1 .

Proposition 5.9. *(Effect of the value of net borrowing)*

The sign of the effect of α_1 on SDV depends on the difference between $\bar{g}$ and r .

Assuming $r = r_C$ and $0 < \psi + \alpha_1$ SDV is an increasing function of α_1 if $\bar{g} \leq r$ and it is a decreasing function of α_1 if $r \leq \bar{g}$.

Proof. Appendix B.1. □

The intuition for this result is similar to ψ , but the effect of α_1 is simpler in that it is independent of a default-triggered crisis. Again the magnitude depends on $\bar{g} - r$, d and h .

Proposition 5.10. *(Effect of the value of default)*

SDV is an increasing function of α_2 .

Proof. The derivative with respect to α_2 is 1, so SDV is increasing in this parameter. □

5.3.2 Magnitude of effects

Table 5.4 calculates SDV for fundamental parameters at the minimum, mid-range and maximum of their considered parameter bounds. The marginal effects of each fundamental parameter (rows) are gauged by varying the given fundamental within its allowed parameter bounds (columns 2 and 3) holding every other fundamental parameter fixed at their baseline values. SDV are reported for three points in each parameter range (columns 4-6) and these are used to calculate the effect on SDV for the full range (column 7: SDV difference at maximum minus minimum), between the minimum and mid-point and between the mid-point and maximum (columns 8 and 9). These latter SDV effects are useful to check potential non-linearity in the effect: whether the effect is materially different at low versus at high parameter values.

Table 5.4 reveals important differences in the magnitude of parameter effects. Real interest rates and political economy utility of default stand out as large positive effects on SDV, both r and α_2 already tipping SDV into default territory at the maximum of their allowed range (with all other parameters fixed at baseline).

On the other hand, the largest decreases come in terms of default-crisis loss ν_1 and crisis duration T (when a longer crisis is expected then the value of repayment increases relative to

Table 5.4: Variation of SDV within fundamental parameter bounds

fundamental	range		SDV			$\partial SDV / \partial Z$			narrative
	Zmin	Zmax	at Zmin	at Zmid	at Zmax	diff	diff L	diff H	
$\bar{g}$	0.00	0.08	-0.03	-0.08	-0.14	-0.11	-0.10	-0.12	decrease
ν_1	0.00	0.25	-0.02	-0.13	-0.31	-0.29	-0.21	-0.37	large decrease
ν_2	0.00	0.25	-0.08	-0.09	-0.12	-0.04	-0.03	-0.05	small decrease
β	0.50	0.99	-0.04	-0.08	-0.16	-0.12	-0.08	-0.16	decrease
T	1.00	100.00	-0.03	-0.10	-0.23	-0.20	-0.14	-0.27	large decrease
r	-0.08	0.10	-0.23	-0.08	0.01	0.25	0.30	0.20	large increase
d	0.10	1.30	-0.07	-0.08	-0.12	-0.06	-0.04	-0.07	small decrease
ψ	0.00	0.85	-0.08	-0.08	-0.09	-0.01	-0.01	-0.01	small decrease
α_1	-0.50	1.50	-0.07	-0.08	-0.10	-0.04	-0.04	-0.04	small decrease
α_2	-0.20	0.20	-0.28	-0.08	0.12	0.40	0.40	0.40	large increase

Sources: author's compilation.

Notes: The table shows simulated effects of fundamentals on SDV (strategic default value). Rows pertain to fundamental parameters. The first two columns report the parameter minima and maxima. The next three columns show the simulated SDV values with all model parameters at baseline and the given fundamental varied from its minimum to mid-range and maximum value levels. Based on these numbers, the next three columns calculate how SDV changes in the parameter: first the total change in SDV from Zmin to Zmax, then (to investigate possible non-linearity of effects:) at the lower half of the range (Zmid-Zmin) multiplied by 2, then at the upper half of the range (Zmax-Zmid) multiplied by 2. The last column provides narrative.

default), but increasing patience β and trend growth $\bar{g}$ also significantly decrease SDV compared to the baseline.

Interestingly, the effects of d , ψ , α_1 seem very modest when other parameters are fixed at the baseline values. Model assumptions and more formal calculations suggest that by varying other parameters these effects can substantially change. This is explored under the next heading.

Based on the results, non-linearity in SDV effects (of the form that effects are significantly different at different values of the fundamental parameter) appears to be a minor issue.⁴⁷ Of course, this is a consequence of the chosen model specification. Perhaps increasing risk aversion would add some non-linearity to effects, but this is not explored further at this point.

It should be emphasized that close to linear effects of these parameters on SDV do not translate into linear effects on the probability of default. On the contrary, this supports the case for the log-linear specifications for sovereign spreads equations that is characteristic of emerging market empirical studies and weakens the case for the linear specifications in eurozone empirical studies (see Chapter 4).

5.3.3 Parameter interactions

The objective of the thesis is to investigate whether changes in the underlying circumstances could cause a significant shift in the (estimated linear) effect of fundamentals on sovereign credit risk. One possibility is that fundamentals interact with each other and the change in an

⁴⁷Splitting the parameter range in two provides only a crude estimate of potential variation in effects. I therefore conducted a more refined analysis plotting the effects continuously in the allowed range for each parameter. This analysis confirms the finding reflected in Table 5.4 that non-linearity is not an important issue for most fundamentals. The only exceptions are the crisis duration and time preference parameters (β , T). These figures are not published here to save space.

unobserved fundamental (or one measured with error) shifts the measured effect of the other fundamental with which it interacts.

In the following I investigate, which parameter interactions appear important from the view-point of the considered theoretical model. Model assumptions, of course, already determine how various parameters may interact, the purpose of this analysis is to also check which of the assumed interactions are important conditioned on parameter restrictions, i.e. taken somewhat closer to the data.

Table 5.5: Fundamental interaction effects on SDV

		Z ₁ effect at baseline									
		$\bar{g}$	r	d	ψ	h	α_1	α_2	ν_1	ν_2	g_C
		-0.11	0.32	-0.09	0.01	-0.04	-0.04	0.40	-0.30	-0.04	-0.00
		Z ₁ effect at Z ₂ minima and maxima									
Z ₂		$\bar{g}$	r	d	ψ	h	α_1	α_2	ν_1	ν_2	g_C
$\bar{g}$	min	-0.11	0.32	0.03	0.07	0.06	0.10	0.40	-0.31	-0.04	-0.00
	max	-0.11	0.31	-0.24	-0.06	-0.16	-0.19	0.40	-0.28	-0.04	-0.00
r	min	-0.10	0.32	-0.42	-0.14	-0.43	-0.40	0.40	-0.28	-0.04	-0.00
	max	-0.11	0.32	0.15	0.12	0.15	0.21	0.40	-0.30	-0.04	-0.00
d	min	-0.02	0.06	-0.09	0.00	-0.01	-0.01	0.40	-0.29	-0.01	-0.00
	max	-0.29	0.80	-0.09	0.03	-0.12	-0.10	0.40	-0.31	-0.10	-0.00
ψ	min	-0.07	0.20	-0.10	0.01	-0.06	-0.04	0.40	-0.30	-0.05	-0.00
	max	-0.19	0.53	-0.07	0.01	-0.01	-0.04	0.40	-0.29	-0.01	-0.00
h	min	-0.01	0.10	-0.04	-0.01	-0.04	-0.04	0.40	-0.29	-0.00	-0.00
	max	-0.29	0.69	-0.18	0.05	-0.04	-0.04	0.40	-0.30	-0.10	-0.00
α_1	min	0.04	-0.08	-0.05	0.01	-0.04	-0.04	0.40	-0.29	-0.04	-0.00
	max	-0.25	0.70	-0.14	0.01	-0.04	-0.04	0.40	-0.30	-0.04	-0.00
α_2	min	-0.11	0.32	-0.09	0.01	-0.04	-0.04	0.40	-0.30	-0.04	-0.00
	max	-0.11	0.32	-0.09	0.01	-0.04	-0.04	0.40	-0.30	-0.04	-0.00
ν_1	min	-0.12	0.32	-0.09	0.01	-0.04	-0.04	0.40	-0.30	-0.04	-0.00
	max	-0.08	0.32	-0.11	0.02	-0.05	-0.04	0.40	-0.30	-0.05	-0.01
ν_2	min	-0.11	0.32	-0.04	-0.02	-0.00	-0.04	0.40	-0.29	-0.04	-0.00
	max	-0.11	0.32	-0.13	0.03	-0.07	-0.04	0.40	-0.30	-0.04	-0.00
g_C	min	-0.11	0.32	-0.09	0.01	-0.04	-0.04	0.40	-0.29	-0.04	-0.00
	max	-0.11	0.32	-0.09	0.01	-0.04	-0.04	0.40	-0.30	-0.04	-0.00
π_c	min	-0.12	0.28	-0.02	-0.01	-0.01	-0.02	0.40	-0.01	-0.00	0.00
	max	-0.09	0.41	-0.28	0.05	-0.12	-0.09	0.40	-0.99	-0.13	-0.00
π_C	min	-0.11	0.32	-0.10	0.01	-0.04	-0.04	0.40	-0.29	-0.04	-0.00
	max	-0.11	0.18	-0.03	0.04	-0.02	0.03	0.40	-0.32	-0.04	-0.02
β	min	-0.02	0.08	-0.04	0.01	-0.02	-0.01	0.40	-0.16	-0.02	-0.00
	max	-1.17	2.83	-0.27	-0.06	-0.17	-0.21	0.40	-0.34	-0.04	-0.00
T	min	-0.12	0.29	-0.04	-0.00	-0.02	-0.02	0.40	-0.09	-0.01	-0.00
	max	-0.09	0.39	-0.24	0.05	-0.10	-0.08	0.40	-0.86	-0.11	-0.00

Sources: author's compilation.

Notes: The top panel reports table shows effects of fundamentals (Z_1) at the baseline setting (large effects highlighted). The rest of the table shows the effects of Z_1 fundamentals on SDV (Z_1 , columns) at minimum and maximum values of other fundamentals (Z_2 , rows). Effects that are significantly different from the baseline effect are highlighted.

Table 5.5 shows how fundamental effects on SDV change as other parameters (in rows) are varied through their allowed bounds. The table reveals quantitatively significant effects of several parameter interactions.

Varying trend growth and real interest rates within their bounds changes the effects of d , ψ , h , α_1 (respective columns) significantly. In fact the effects on SDV switch signs at the extremes. In case of d , the baseline negative effect on SDV (-0.09) turns into a positive value at trend growth minimum (0.03) and at r maximum (0.15). In the other extremes of $\bar{g}$ and r the effect of d on SDV is large negative. When $\bar{g} - r$ is large then an increase in ψ , α_1 and h reduce SDV, i.e. the willingness to repay increases.⁴⁸

Another group of influential interactions concern the possibility of a default-triggered crisis. Parameters related to such a crisis are π_c , ν , d and ψ and h . When a default can trigger a crisis related to domestic debt holdings (π_c and ν_2 are large), an increase in d and h and a decrease in ψ are associated with larger decreases in SDV, i.e. domestic bonds act as a commitment device. These varying effects are apparent from the rows of the table with minimum and maximum π_c and ν_2 . When these parameters are close to zero, d , ψ and h have negligible effects on SDV (therefore their effect due to net capital flows are small), whereas these effects increase materially, when default-crisis is allowed.

Finally, effects of how the short-term vs the long-term are perceived are important for the effects of several parameters. The crisis is assumed to only affect the short-term, so fundamentals that have opposing sign of effects in crisis and outside of crisis will have overall effects that depend on the length (T) and relative utility value (β) of the short-term. Generally, as β decreases towards its lower range, fundamental effects appear to decline in absolute value. Compared to these values, at the upper bound $\beta = 0.99$ the effect of r , $\bar{g}$ and d are orders of magnitude larger. Similarly, the fundamental effects are very different when crises are expected to be short compared to when their effects are close to permanent. Again the effects are much larger at the upper bound (long crisis), but T impacts a somewhat different set of fundamentals. The effects increase around tenfold for ν_1 , ν_2 and somewhat less for d . In contrast to β , however, the effects of r and $\bar{g}$ are relatively stable as T varies.

5.3.4 Scenario analysis

A caveat of the analysis based on Table 5.5 is that the effects of fundamentals are gauged as a single parameter is varied from its baseline value. However, several fundamentals may change simultaneously over time (and across cross-section units) and this might lead to different effects compared to variation of parameters individually.

To address this possibility, the simultaneous effects of parameters ψ , d and for a few values:

⁴⁸Note that this follows from the structure of the model and the assumption that government calculates with a constant trend debt ratio. A default reduces debt in the model on the long term and this is perceived as positive only when there is a capital outflow (or adverse domestic redistribution, α_1) associated: i.e. when $\bar{g} - r$ is negative. Under these circumstances a higher debt level, haircut and $\psi + \alpha_1$ increase the motivation to default.

Figure 5.1: SDV contours in allowed d, ψ ranges (normal state)

Sources: author's compilation.

Notes: The figure plots SDV contour lines for four scenarios of real interest rates r , trend growth $\bar{g}$, default-triggered crisis probability π_c (upper/lower, left/right panels) for the allowed parameter ranges of public debt ratio d (horizontal axes) and share of external debt ψ (vertical axes). SDV levels are identified on color bars next to each subplot. The $SDV = \{-0.001, 0, +0.001\}$ contours of black dot-dash lines depict the boundary of the default decision. In each case the initial state is normal: $\pi_C = 0$.

The messages of these plots are best understood by considering the direction in which SDV increases (imagine lines perpendicular to contours). These identify the sign of effect that the debt ratio and external share have on SDV. The slope of contours is also informative: vertical contours mean d has a large effect compared to that of ψ ; horizontal contours denote relative larger effects of ψ . Finally the colormaps point out the minimum and maximum and hence the ranges SDV can take under various circumstances.

$r, \bar{g}, \pi_c$ are investigated in the contour plots of Figure 5.1. The four subplots of the figure depict SDV contour lines in the $d - \psi$ plane. Each plot considers different scenarios of normal interest rates (r), trend growth ($\bar{g}$) and default-triggered crisis probability (π_c). The initial state is set to be normal, i.e. initial crisis probability is $\pi_C = 0$.

In particular, the upper panel considers the case when the default choice is expected to lead to a crisis with a low, 5 percent, probability. In contrast, the lower panel assumes that the default-triggered crisis has a 95 percent expected probability. The left-hand plots consider the case when trend growth is above real interest rates and the right-hand plots depict SDV when trend growth is below real interest rates.

Within these settings, the model predicts default to occur only when default-crisis has a low probability and real interest rates are high relative to trend growth (upper panel, right-hand plot). When these conditions are met, the government chooses default for external-only public debt levels higher than 20 percent of output and domestic-only debt levels higher than 40 percent of output. Since this figure is set in an initial normal period $S = N$ real interest rates would need to be consistently higher than trend growth on the long-term and outside of crisis with low chance of crisis costs. In this case government would choose default to reduce its burden of debt

service.⁴⁹

Repayment is predicted in all other (more realistic) cases: SDV contours are negative for all permitted values of d and ψ . In contrast to the top right subplot, where SDV is increasing in d , in the three other cases higher d results in lower SDV values. The effect of ψ is positive in the right hand plots (when $r > \bar{g}$) and close to zero with ambiguous sign in the left-hand plots.

As colormaps point out, the sensitivity of SDV to both d and ψ factors is clearly larger in the case when there is a higher chance of a default-crisis: SDV spans a much smaller range in the low default-crisis probability cases (top panel) compared with the high default-crisis probability case (bottom panel). This has the important implication that when π_c is low, strategic default may still occur in the model due to political economy disutility of repayment captured by the parameter α_2 and a large negative α_2 could prevent a default when $r > \bar{g}$.⁵⁰ However, when π_c is high, α_2 allowed ranges are not enough to tip SDV into default territory and are therefore an irrelevant factor in strategic default determination.

Fundamental effects in crisis

Figure 5.2 shows the same plots for the (initial) crisis state, $S = C$. The top panel plots that feature low chance of default-triggered (added) crisis are largely similar to Figure 5.1: when $\bar{g} > r$ (top left) d has a negative effect on SDV, whereas ψ is largely immaterial; when $\bar{g} < r$ both d and ψ have an increasing effect on SDV.

When there is a high default output loss probability (bottom plots) the contours are somewhat different compared to the normal state. The external share here has a significant positive effect in the $\bar{g} > r$ (top left) scenario especially at higher d levels (in contrast to having no effect in $S = N$). When $\bar{g} < r$ ψ has an increasing effect on SDV as before, but the effect of d depends on ψ . In this case a mostly external debt results in a positive d effect on SDV, because in this case higher debt increases consumption loss due to capital outflow (since $\bar{g} < r$). If debt is domestic then a higher the debt level decreases SDV because of the fear that a default would trigger a crisis.

There are important quantitative differences in fundamental effects compared to the normal state. In the initial crisis, the high trend growth – low default cost scenario (upper left subplot) SDV levels are much less varied restricted to the $[-0.012, -0.032]$ range, which is the upper end of the much larger normal state range. This implies that high trend growth advantages in favor of repayment are less valued in a crisis, especially at high debt levels. This may be important

⁴⁹The predictions would be the same without the assumption of constant debt ratio. Lowering net borrowing to decrease the debt ratio would reduce utility, so – given the low output costs of default of the upper-right plot scenario – the sovereign would default instead to arrive at a lower debt level.

⁵⁰Recall that α_2 was considered in the $[-0.2, 0.2]$ interval. The upper bound is consistent with a government hostile to repayment so much that it is indifferent between the (relative) disutility of repaying or defaulting but also suffering a medium scale economic crisis (based on Laeven and Valencia, 2012, a 20 percent output loss compared to trend on a four-year time span is slightly below the median)). The lower end of the range is consistent with a government valuing repayment so much that it would be indifferent between the disutility of a default and suffering a medium-scale crisis.

Figure 5.2: SDV contours in allowed d, ψ ranges (crisis state)

Sources: author's compilation.

Notes: The figure plots SDV contour lines for four scenarios of real interest rates r , trend growth $\bar{g}$, default-triggered crisis probability π_c (upper/lower, left/right panels) for parameter ranges of public debt ratio d (horizontal axes) and share of external debt ψ (vertical axes). The $SDV = \{-0.001, 0, +0.001\}$ contours of black dot-dash lines depict the boundary of the default decision. In each case the initial state is crisis: $\pi_C = 1$. See further notes in Figure 5.1.

regarding the relative effect of the political economy stance (parameter α_2) toward default. The plot tells us that without significant default output costs, political preferences toward repayment may be more important factors than debt levels, debt structure and real growth vs real rates in a crisis. A significant chance of a default-triggered crisis deters politically-motivated sovereign defaults in either the normal or crisis states, when trend growth is significantly above real interest rates.

In the crisis state with low trend growth (right hand plots) the presence of output costs related to domestic bondholdings are crucial in determining default. When default output loss is considered to be low, default occurs already at low debt levels. However, when default is assumed to result in significant added output costs, then sovereign defaults would only occur in countries with extreme large external debt levels, in fact higher than ranges considered in the parametrization, i.e outside of the general ranges seen in emerging market and advanced country data. Political economy stance (α_2) becomes important in both of these cases: a strong market-friendly attitude can forestall default even for countries with high external debt levels, whereas a hostile attitude can lead to a default even for countries with low debt ratios or domestic debt.

Figure 5.3 turns to the issue of how crisis depth and crisis duration affect the willingness to repay decision in both the low default-crisis probability (left hand plots) and high default-crisis probability (right hand plots) scenarios. Crisis depth is measured by four different parameters: g_C , r_C , ν_1 and $\bar{g}$ (plot vertical axes).

Figure 5.3: Effects of crisis depth variables and crisis duration on SDV

Sources: author's compilation.

Notes: The figure plots SDV contour lines for two scenarios (low and high probability of default-triggered crisis, π_c , left vs right plots). Each plot measures SDV at different crisis depth (vertical axes: g_C , r_C , ν_1 , $\bar{g}$) and crisis duration levels (horizontal axes: T). SDV levels are identified on color bars next to each subplot. The $SDV = \{-0.001, 0, +0.001\}$ contours of black dot-dash lines depict the boundary of the default decision. In each case the initial state is crisis: $\pi_C = 1$.

The slope of contours tell whether crisis depth (horizontal) or crisis duration (vertical) has a relatively more important effect. The slopes tell us that crisis duration tends to matter more when the default-triggered crisis has a high probability (right-hand plots) and is not much relevant when such a crisis is not probable (left-hand plots). This again suggests that standard

economic setbacks represented by the initial crisis $S = C$ state have a relative small effect on SDV compared to fundamentals and compared to a default-triggered crisis if these setbacks can be considered temporary.

The (initial) crisis state output loss g_C appears to have a negligible affect on SDV (see the color bar range) when default-triggered crisis is not expected (top left plot). In the high default-cost scenario (top right plot), the effect of the g_C parameter is still insignificant for small values of T (SDV contours are vertical), and becomes somewhat more relevant when the crisis is long-lasting.

Real interest rates have a much larger effect than g_C . When default-crisis probability is low, government chooses default at real interest rates above 7-10 percent. Political preferences in favor of repayment (positive α_2) may however significantly raise the bar for a default. When default is perceived to have high costs, then default is unlikely.

The default-crisis output loss parameters, ν_1 and ν_2 , are crucial determinants of the sovereign default decision even when default-crises are perceived to have a small probability. In this case α_2 could also play an important role as colormaps tell us that in such a scenario SDV is within the bounds of the α_2 parameter. When default-crisis has large probability, even very small values of ν_1 and ν_2 parameters result in a guaranteed repayment choice.

Finally, different levels of trend output growth (these have a smaller allowed range than the other three crisis depth variables) may contribute significantly to the default decision in case of low default-crisis probabilities. The range of SDV in this scenario (bottom left plot) is again quite small to promote the relevance of political preferences. In case of high default-crisis probability, crisis duration becomes more important and trend output becomes a secondary issue.

CHAPTER 6

Extension to funding liquidity crises (Model II)

The model of the previous sections (Model I) considered sovereign default from the classical willingness to pay perspective in normal and financial crisis settings.

This chapter presents a modification of the model (Model II), which adds the ability to pay aspect: the possibility that a government can default on debt obligations even though it would choose to repay. The crisis setting in this model aims to incorporate funding liquidity crisis spells: time periods, when the government lacks market access and has to turn to alternative sources of funding if it wants to avoid a default.¹

Chapter 2 reviewed the academic literature that investigated the ability to repay aspect. The ability to repay was on one hand considered from a solvency aspect, in which fiscal adjustment is for some reason not flexible, so that the primary balance under some circumstances cannot be sufficiently increased to forestall explosive debt dynamics.²

Second, as already argued by early papers of the literature (e.g. [Sachs, 1983](#); [Krugman, 1985](#); [Calvo, 1988](#)), individual investors need to consider the overall market supply of funding, which may lead to multiple equilibria and a self-fulfilling prophecy of a funding shortfall (investor expectations of other investors not lending, which results in a no-lending 'bad equilibrium'). Market liquidity shocks, restrictive monetary policy in core countries, increasing general risk aversion or simply market rumors could all reduce supply of market funds for sovereign bond issuances leading to higher interest rates and thus an increased motivation to default. Capital flight and exchange rate depreciation could then ensue, which can also steer the government toward a default, because of an increase in the external debt stock (foreign exchange debt is usually foreign held) and a drop in real growth as a credit crunch develops in the financial sector.

The potential unavailability of market funding is not guaranteed to lead to default, because

¹Note that this is different from the general treatment in the literature, which assumes that market exclusion is a consequence of the government decision. Here, the market exclusion occurs before the government decision. This modification aims to accommodate recent crisis experiences, in which several countries were faced with lack of market funding, but international assistance and central bank refinancing (also aided by FX swap facilities) was enough to avert default. Appendix C.2 provides a more complicated and realistic framework, in which it is ultimately the government that decides on turning to the IMF (self-selecting into market exclusion), but usually as a result of high market interest rates (i.e. lack of funding liquidity). Interest rates in that model are endogenously derived, which also consider investor expectations of a potential for disagreement with international lenders about bailout conditions (itself a function of SDV).

²E.g. in the model of [Ghosh et al. \(2013\)](#) fiscal fatigue characterizes the fiscal reaction function: as the debt ratio increases the primary balance increases but at a slowing rate, leading to a debt ceiling above which debt dynamics are explosive. Most papers in this strand are rather agnostic about the motives of dynamic relationships and only estimate them from the data (for instance [Bohn, 1998](#); [Genberg and Sulstarova, 2008](#); [Mendoza and Ostry, 2008](#)), but [Bølstad and Elhardt \(2017\)](#) rationalizes such constraints on fiscal adjustment on political grounds.

central bank lending of last resort and international financial assistance may still provide the necessary funding to service debt. In case of central bank lending the amount of official reserves vs oncoming foreign exchange funding needs (foreign currency debt maturities, current account deficits) are important, because central banks can more easily provide domestic currency funding.³ When ample reserves are available, this reduces the probability of a 'bad equilibrium' developing. International assistance (e.g. IMF bailouts) crucially depends on terms of conditionality and the willingness of the government to comply with these. International lenders are likely to demand more painful reforms, when debt is considered less sustainable, i.e. when debt is high and its dynamics are adverse. Also the sovereign is less likely to comply with conditions when it is already closer to deliberating default (SDV is negative but near 0).

If there are inadequate market and central bank funds and negotiations with international creditors fail, then the sovereign could enter a phase of disorderly default in which the government cannot service oncoming liabilities. Then, the government has to immediately rebalance its budget or resort to monetary finance both of which are likely to entail significant output costs and disutility for residents.⁴

The goal of this chapter is to incorporate some of the key aspects of a funding liquidity crisis and a disorderly default induced by a liquidity-shortfall into the model. The key simplifications of the framework in Model I are maintained, so dynamic aspects of self-fulfilling crises and debt sustainability are not incorporated.⁵ A further simplification is that I consider external debt (debt held by non-residents) and foreign currency debt to be equivalent. Although there is a positive association between the two (because usually foreign-currency issuances are issued abroad to a foreign investor community), there are significant foreign holdings of domestic currency debt (it has increased in the past decades to around 20 percent in emerging markets according to the dataset by [Arslanalp and Tsuda, 2014](#)). Also, domestic holdings of foreign currency issuances may be significant in dollarized economies, where governments tended to issue in foreign currency to increase demand, but data in this direction is not available.

The key benefit of introducing the funding liquidity crisis into the analysis is that it adds two important aspects to how debt and debt structure affect default decisions: high foreign-currency debt levels increase the prospect of funding liquidity shocks, because central bank reserves may not be able to offset oncoming foreign-currency obligations. Also high debt levels lead to bailout

³Rules on monetary financing may prohibit such act of lending as last resort and also the credibility of the central bank (how anchored inflation expectations are) are also important in this regard. I do not consider these factors here.

⁴Since disorderly defaults often involve larger losses to investors and governments alike, lengthier ensuing crisis ([Asonuma and Trebesch, 2016](#)), governments usually aim to come to terms with international lenders. Even if disorderly defaults are rarely optimal for either parties, they are feared to happen. In the Greek debt crisis, for instance, there were numerous episodes, when negotiations were concluded just in time to provide last-minute bailout financing to prevent a disorderly default. A risk in these instances was the arrival of adverse new data (e.g. low tax revenues, low growth rates, high fiscal spending), then negotiations would fail to be concluded in time. Another recurrent risk was the change in political mandate for either the debtor government or international lenders that could drive a wedge between negotiating positions.

⁵Appendix C.2 adds important stochastics and dynamics to this aspect as well.

conditionality that is more strict, which leads to difficult negotiations with international lenders and less commitment to repay. Another benefit of introducing funding crisis is that it is difficult to account for the existence of large domestic debt seen in advanced countries without costs of external debt issuance other than arising from difference of real rates and trend growth. The probability of an adverse funding liquidity crises depending on external debt levels limits the desire of sovereigns to issue debt abroad.

With respect to Model I, the key differences are as follows. First, the initial crisis regime represents a period of funding liquidity problems (instead of a financial crisis as before) in which the sovereign is excluded from the market and turns to international assistance for funding. Entering this regime is partly tied to domestic fundamentals, notably reserves and external debt (to proxy levels of foreign currency funding needs). Within the funding crisis regime default may be strategic, the choice of government, but it could also occur stochastically. Second, output shocks are more complex than in Model I. Third, net foreign borrowing is assumed to be zero in default, a simplification compared to Model I (and reality), but is in line with the usual assumption of autarky in default in the literature. Fourth, net foreign borrowing is assumed to be negative and increasing with debt in a bailout (conditionality). Finally, two types of haircuts, investor losses on bonds and debt relief, are distinguished.

The first part of the chapter is structured similarly to Chapter 5. The first two sections discuss the updated assumptions compared to Model I and baseline settings of new parameters in Model II. The third section turns to fundamental effects on SDV under various scenarios with special attention on crisis parameters representing the intensity of funding liquidity pressures. Section 6.4 turns to other policy parameters: the target public debt ratio, the external share of debt, the haircut given a default and the political economy parameter mentioned above. A brief discussion of political economy effects follows. Although this part of the thesis is theoretically motivated, I devote a section to assess the empirical validity of Models I and II. Section 6.6 summarizes results and provides some testable implications that will later be useful, in the empirical part of the thesis.

6.1 Assumptions

Several assumptions and much of the notation of Section 5.1 can be maintained for this analysis, though some of the parameters are redefined to align with aspects of funding liquidity.

The initial crisis state ($S = C$) and its probability of occurring, π_C , refer to the regime of a funding liquidity crisis, in which the country loses its ability to fund itself without international assistance. The probability of entering such a crisis is parameterized as a logistic function with an element c_0 not related to domestic fundamentals and thought of as external circumstances (international liquidity, risk appetite, core country interest rates, rumors). Another element with scale c_1 depends on the difference of the external component of the debt ratio ψd (this term proxies oncoming external and foreign currency funding needs) and official reserves of the cen-

tral bank, res . When c_1 is large, then sufficient reserves compared to foreign currency funding needs lowers the probability of losing market access and having to turn to international bailout funding.

The default-triggered crisis state $s = c$ has a similar meaning as in Model I: it is a lower endowment state in default (I refer to it here as a disorderly default). As in the initial normal state $S = N$, this occurs with probability π_c conditional on the sovereign choice of $\lambda^g = 1$. The probability π_c is assumed to be independent of fundamentals.

In the funding liquidity crisis state $S = C$, however, a disorderly default state $s = c$ could occur as a result of two distinct factors. First, as before, the sovereign may choose to default and could be unfortunate to end up in this state. Second, irrespective of the government choice to remain in the contract (repay or default), liquidity conditions and unsuccessful negotiations with international lenders can result in a disorderly default with probability λ^l . As a simplification, the model does not assume parameterized fundamental links to this parameter. Overall, selection into the disorderly state has a probability of $\lambda^g \pi_c^g + \lambda^l$ in the funding crisis state.

Other parts of the Assumption on government utility are the same. The government maximizes period 0 utility by choosing optimal d and ψ and period 1 utility by choosing λ^g , the default decision, and h^g , the size of debt relief in default (i.e. the ratio by which debt stock is reduced in the restructuring process).

Assumption 6.1a. (*Government utility*)

$$\begin{aligned}
U_0 &= \max_{d, \psi} \left\{ \sum_S \pi_S E_0[U_S(d, \psi)] \right\}, & U_{1|S, d} &= \max_{\lambda^g, h^g} \{ E_0[U_S|S] \}, \\
E_0[U_N] &= (1 - \lambda^g) V_N^R + \lambda^g \sum_s \pi_s V_{Ns}^D, \\
E_0[U_C] &= (1 - \lambda^l) \left[(1 - \lambda^g) V_C^R + \lambda^g \sum_s \pi_s^g V_{Cs}^D \right] + \lambda^l V_{Cc}^D, \\
V_S^R &= \sum_{t=1}^{\infty} \beta^{t-1} u(v_{S,t}^R) = \sum_{t=1}^{\infty} \beta^{t-1} u(Y_{S,t}^R + NFB_{S,t}^R + \alpha_1 NB_{S,t}^R), \\
V_{Ss}^D &= \alpha_2 + \sum_{t=1}^{\infty} \beta^{t-1} u(v_{Ss,t}^D) = \alpha_2 + \sum_{t=1}^{\infty} \beta^{t-1} u(Y_{Ss,t}^D + NFB_{Ss,t}^D + \alpha_1 NB_{Ss,t}^D), \\
S \in \{N, C\} \quad s \in \{n, c\}, \quad \pi_C &= \frac{1}{1 + \exp(-c_0 - c_1(d\psi - res))}, \\
0 &\leq v, v + \alpha_2,
\end{aligned}$$

where d, ψ, res are debt ratio, share of external debt, and reserves-to-output; λ^g is the default choice, h^g is debt relief; S, s, π_S, π_s are initial and post-default states of nature and their probabilities; c_0 and c_1 are parameters of π_C ; π_c is conditional on $\lambda^g = 1$ in $S = N$ and unconditional on λ^g in $S = C$; $u(\cdot), v, \beta$ are utility function, voter payoffs and subjective discount factor, respectively; Y, NFB, NB represent output endowment, net foreign borrowing

and net borrowing.

Due to the above changes, equations (5.1) and (5.2) are replaced in the funding liquidity crisis state ($S = C$) by:

$$\begin{aligned} U_C &= (1 - \lambda^l)[(1 - \lambda^g)(1 - \pi_c^g)V_C^R + \lambda^g(1 - \pi_c^g)V_{Cn}^D \\ &\quad + \lambda^g\pi_c^gV_{Cc}^D] + \lambda^lV_{Cc}^D, \\ SDV_C &= (1 - \lambda^l)[(1 - \pi_c^g)V_{Cn}^D + \pi_c^gV_{Cc}^D - V_C^R]. \end{aligned} \quad (6.1)$$

Default policy is still determined by SDV as defined by Definitions 5.1 and 5.2, but it has a different structure in the crisis regime than SDV_C in Section 5.1. In Model II, the probability of entering the default in $S = C$ is partly independent of the government choice to default (by λ^l). Therefore, SDV is scaled down by a factor of $1 - \lambda^l$. Otherwise the structure of the default decision is the same as in Model I: it depends on the probability-weighted sum of default utility minus utility in repayment.

The endowment process adds several new elements compared to Model I. As before, the normal repayment state NR and the long-term state receive an endowment consistent with the trend growth path. In other (short-term) states, there is a first period output shock and after that the resulting output gap is maintained for the duration of the short-term. These short-term states now refer specifically to various types of sovereign crises. This is either a period of restructuring in default states (which is concluded by government debt relief), the states ND and CD , or it is a case of funding liquidity crisis and repayment, CR , which represents the state of being excluded from the market and receiving international official funding, but repaying debt in full.

Output shocks involve three components. First, as before ν_1 represents a shock for disorderly default states $s = c$ that is independent of fundamentals. The second shock to output is related to financial sector losses on domestically held debt securities. The value of such losses are assumed to be $g_{c2} = \nu_2 d(1 - \psi)h^m$ in the disorderly default states (as in Model I), but it is also assumed to similarly affect the $s = n$ state in the funding crisis, $S = C$. The rationale behind this is that in Model II, the crisis is specifically thought of as a scenario where investors turn away from government bonds, i.e. bond prices must be affected, whereas the more general financial (banking or currency) crisis in Model I may or may not depress bond prices significantly. In the funding crisis with repayment (i.e. the bailout scenario), the output loss due to bond writedowns is smaller and is assumed to be $g_{c2}\lambda^l$ in line with the assumption that in this case an unwanted liquidity-default occurs with probability λ^l .

The third shock adds adverse effects on output due to a potential currency crisis. I assume that the sovereign crisis in the $S = N$ state entails large currency depreciations only when $s = c$, but exchange rate depreciation is characteristic of all states of a funding crisis, since this state already represents a period of capital flight. The third output shock $g_{c3} = \nu_3\nu_2\psi$ represents the added strains on the financial sector and domestic lending (therefore the ν_2 term) that follows from either of (i) non-performing loans of residents with foreign exchange liabilities rising or

(ii) residents converting savings into foreign currency. Both factors arguably increase with the level of financial dollarization in the economy, which I assume to be properly proxied by the external share of public debt. I assume that international assistance reduces this component to its half (i.e. in the funding crisis repayment and orderly default vs. disorderly defaults).

Assumption 6.2a lists the first-period growth rates in each state. Other attributes of the endowment process remain unchanged compared to Assumption 5.2.

Assumption 6.2a. (*Endowment growth rates*)

$$g_{Ss} = \begin{cases} 0, & \text{if } S = N \text{ and } \lambda^g = 0, \\ 0, & \text{if } Ss = Nn \text{ and } \lambda^g = 1, \\ \nu_1 + g_{c2} + g_{c3}, & \text{if } Ss = Nc \text{ and } \lambda^g = 1, \\ g_{c2}E[\lambda^l] + g_{c3}/2 + g_{c4}, & \text{if } S = C \text{ and } \lambda^g = \lambda^l = 0, \\ g_{c2} + g_{c3}/2, & \text{if } Ss = Cn \text{ and } \lambda^g = 1 \text{ and } \lambda^l = 0, \\ \nu_1 + g_{c2} + g_{c3}, & \text{if } Ss = Cc \text{ and } \lambda^g = 1 \text{ or } \lambda^l = 1, \end{cases}$$

$$g_{c2} = \nu_2 d(1 - \psi)h^m,$$

$$g_{c3} = \nu_3 \nu_2 \psi,$$

$$0 \leq \nu_1, \nu_2, \nu_3, \quad 0 < E[\lambda^l], h^m \leq 1,$$

where g_{Cc} denotes the first-period output loss as before with ν_1 , ν_2 , ν_3 parameters scaling a disorderly default loss component ν_1 ; financial sector components due to losses on government bonds g_{c2} (with market losses of h^m) and foreign exchange depreciation g_{c3} , and output loss due to austerity measures, g_{c4} .

The last two assumption blocks are simpler than in Model I.

Net borrowing is the same as before in the normal repayment state and the long-term. However in all default states net borrowing is assumed to be zero. This is in line with the common assumption in the literature of financial autarky in a default.

In the funding liquidity state with repayment (CR), bailouts come at the price of a negative net borrowing proportional to d and scaled by a parameter ν_4 . Thus net capital outflows amount to $\nu_4 d\psi$ and there is also a political economy disutility of austerity of $\nu_4 d\alpha_1$.

Assumption 6.3a. (*Fiscal and current account balances*)

$$\begin{aligned}
 NB_N^R &= NB_{C,t>T}^R = \tilde{Y}_t \frac{d(\bar{g} - r_{Ss,t})}{(1 + r_{Ss,t})(1 + \bar{g})}, \\
 NB_{C,t \leq T}^R &= \tilde{Y}_t \frac{-\nu_4 d}{(1 + \bar{g})}, \quad NB_{C,t>T}^R = \tilde{Y}_t \frac{d(\bar{g} - r_{Ss,t})}{(1 + r_{Ss,t})(1 + \bar{g})}, \\
 NB_{t \leq T}^D &= 0, \quad NB_{T < t}^D = (1 - h^g) \tilde{Y}_t \frac{d(\bar{g} - r_{Ss,t})}{(1 + r_{Ss,t})(1 + \bar{g})}, \\
 NFB &= \psi NB,
 \end{aligned}$$

where NB_t , NFB_t measure net borrowing (structural fiscal deficit) and net foreign borrowing (positive values consistent with capital inflow), respectively, with r the normal state real interest rate.

Assumption 6.4a. (*Real interest rate*)

$$r_{Ss,t} = r,$$

When interest is paid on debt, it is the normal state real interest rate that is paid.

6.2 Parametrization

There are seven new parameters in this model: res , h^m , λ^l , c_0 , c_1 , ν_3 and ν_4 . For res and h^m I use the historical data set presented in the appendix. The baseline value for res is set to 0.1 in line with the full sample mean on the historical data set, but higher than the median of 6 percent. Bounds are set to 0.01 and 0.3 consistent with the data (see Table A.9). For h^m I use the net present value calculations for default spells provided by Asonuma and Trebesch (2016). Based on the experiences of spells in which h^g is greater than 0, h^m can be well approximated well by the $0.25 + 0.75h^g$ (see Appendix Figure A.8). I set λ^l the way π_c is set: a baseline value of 0.3 (consistent with a mean expectation of a disorderly default after 3 years of international official funding) and wide parameter bounds 0.01-1.

For the two parameters, c_0 and c_1 , entering the logistic equation of the probability of a funding crisis I chose parameter baseline values of -4 and 5 and ranges $[-7, 0]$ and $[0, 10]$. With baseline values for d , ψ and res , these parameters yield a liquidity crisis probability of 2.3 percent, near the empirical frequency around 4 percent. At these debt levels variation of c_0 shifts crisis probability between 0.1 and 56 percent. When c_1 is set to 0 (only external conditions determine π_C , oncoming funding needs and reserves do not), then the extremes of c_0 (very adverse vs very benign external liquidity conditions) vary the funding crisis probability between 0.12 percent and 50 percent. When instead c_1 is at maximum sensitivity no external debt and large reserves restrict funding crisis probability below 5 percent even for large c_0 , while maximum external debt and no reserves result in over 95 percent crisis probabilities.

The ν_3 parameter determines the exchange rate depreciation effect on the initial crisis year growth rate (and the constant annual output loss in the short-term) together with ν_2 and ψ . The ν_3 parameter is set to a baseline of 0.5 with parameter bounds 0 and 1. At the baseline setting for all parameters $g_{c3} = 0.02$. When ψ and ν_2 are at their maximum (i.e the economy is dollarized and the banking sector is vulnerable), then a baseline ν_3 results in an annual output loss of $g_{c3} = 0.11$ and 21 percent when ν_3 is at its maximum as well. The austerity component is calibrated to a 1 percent consumption utility loss under baseline conditions and 4 percent when debt is at its maximum.

The ν_4 parameter is set to 0.03 in the baseline, which represents a fiscal effort of 1.5 percent of output in case of the baseline 50 percent debt ratio. With preferential low interest rates in a bailout, this fiscal effort is thought of as the necessary fiscal tightening that maintains the structural primary balance at the zero level (just like under normal repayment the debt ratio is assumed to be maintained at the same level), i.e countering the effects of a growth slowdown and one-off expenditures related to the crisis, for instance, bank recapitalization.

Since the short-term now denotes the length of restructuring/funding crisis periods, T upper bound is lowered to 15 years (the 95th percentile in the historical data set), while the baseline is kept at 4 years (the mean of sovereign crisis cases).

Baseline SDV

In Model II, based on baseline settings, SDV in the initial normal state regime (setting $c_0 = 0$ and $c_1 = 0$) is -0.115, lower than in Model I (-0.101), and it is -0.067 if the funding crisis is certain to occur, which is higher than the financial crisis state SDV in Model I (-0.076).

The key explanation for the lower SDV in the normal state is that Model II short-term default states are assumed with zero net borrowing (autarky), whereas there is capital outflow in Model I with real interest rates assumed to increase in a crisis. This steers sovereigns toward defaults more in Model I. In Model II there is also an element of output losses due to exchange rate depreciation, which raises the costs of default and hence lowers SDV. Acting in the other direction, but to a lesser extent is the utility loss in the long-term state due to a reduced debt ratio. Because debt relief is smaller in Model II, this lowers the costs of default and so raises SDV.

The funding liquidity crisis SDV is closer to zero (the tipping point necessary for a default) than SDV in the financial crisis of Model I. On one hand, the repayment regime now has an element of fiscal austerity, which reduces the willingness to repay, whereas defaults involve autarky rather than capital outflows. Another important factor here is output losses due to valuation losses on domestic government bondholdings is already realized in the repayment state, even if this effect is smaller than in default.

6.3 Fundamental effects on SDV

The structure of the model is similar to Model I. Therefore identifying fundamental effects can be done in the same fashion as before and these yield similar results in most cases.

For both the initial normal and funding liquidity states the effects on SDV in the short-term are determined by the respective differences between repayment and default values, $V_S^D - V_S^R$, writing V_S^D for the probability-weighted sum of the two default states. The funding liquidity state downweighted due to a scaling factor $(1 - \lambda^l)$ (equation (6.1)), which reduces the value of the difference compared to the long-term and the normal state. The two other key differences are that (i) the funding liquidity state assumes no net borrowing even for repayment (so long-term growth and real interest rates are more relevant in the normal state), (ii) there is the cost of austerity and bond valuation losses (due to λ^l) that decreases the value of repayment and thus generally SDV. As before (see equations (5.3)-(5.7)) the value functions can be written as the logarithm of the term $A = G_{Ss} + dHPR$ using the notations before (see Table 5.3 notes), which is multiplied by the relevant time aggregating term for the short-term and long-term.

A significant difference compared to Model I is that the term $dHPR$ is zero in all (short-term) default states, so fundamental effects on SDV are mostly determined by the difference of effect on output in the repayment versus the default state. The term $dHPR$ is also less important in the long-term compared to before due to the haircut (debt relief: h^g) being relatively smaller in the baseline, consistently with historical experiences.

Most of the effects on SDV, therefore, derive simply from the endowment growth rate assumptions, Assumption 6.2a.

Table 6.1 reproduces Table 5.5 for Model II. Baseline effects of fundamentals (overall and for the normal and funding liquidity crisis states) are shown in the top panel. All fundamentals have the same sign as before except for ψ , which is negative here instead of a marginally positive value before. The effects are very similar in all cases (see top row of top panel).

In terms of important interactions in Model II as well, the effect of trend growth and real interest rates are larger when debt, its external share, the haircut and α_1 are larger, because these increase the value of long-term net capital flows in absolute value. Similarly, when $\bar{g} - r$ is large, then the SDV effects of d , ψ , h and α_1 decrease and switch signs just like in Model I.

Like before, quantitatively important interaction effects originate from output costs due to losses on domestic bondholdings in case of a default. The absolute effects of the group ν_2 , d , h increase together as any of these parameters are increased. The overall effect of ν_3 is relatively small in the baseline, though an increase in this parameter noticeably decreases the effect of ψ on SDV. Recall that the effect of the parameter ν_3 (exchange rate depreciation) reduces output in $S = N$ in the default-crisis state. This effect is larger when ψ and ν_2 are large to incorporate larger problems in financially dollarized economy. In a funding crisis (e.g. the maximum c_0 parameter row), however, the repayment state also suffers output losses due to exchange rate depreciation, moreover nu_3 increases output costs related to bailout conditionality, which drives

Table 6.1: Fundamental baseline and interaction effects on SDV (Model II)

		Z_1 effect at baseline											
		$\bar{g}$	r	d	ψ	res	h^g	α_1	α_2	ν_1	ν_2	ν_3	ν_4
∂SDV		-0.12	0.30	-0.07	-0.05	-0.00	-0.05	-0.02	0.40	-0.30	-0.08	-0.05	0.00
$\partial SDVN$		-0.12	0.31	-0.07	-0.05	0.00	-0.05	-0.02	0.40	-0.30	-0.08	-0.05	0.00
$\partial SDVC$		-0.01	0.05	-0.04	0.03	0.00	-0.07	0.04	0.28	-0.21	-0.07	-0.02	0.05
Z_2		Z_1 effect at Z_2 minima and maxima											
		$\bar{g}$	r	d	ψ	res	h^g	α_1	α_2	ν_1	ν_2	ν_3	
$\bar{g}$	min	-0.12	0.31	0.07	0.01	0.00	0.03	0.13	0.40	-0.31	-0.08	-0.05	0.00
	max	-0.12	0.30	-0.22	-0.11	-0.00	-0.14	-0.19	0.40	-0.28	-0.07	-0.05	0.00
r	min	-0.11	0.30	-0.49	-0.23	-0.01	-0.32	-0.49	0.40	-0.30	-0.08	-0.05	0.00
	max	-0.12	0.30	0.19	0.06	0.00	0.10	0.26	0.40	-0.30	-0.08	-0.05	0.00
d	min	-0.02	0.06	-0.07	-0.07	-0.00	-0.01	-0.00	0.40	-0.29	-0.05	-0.05	0.00
	max	-0.31	0.74	-0.07	0.10	-0.01	-0.14	-0.04	0.39	-0.30	-0.14	-0.05	0.01
ψ	min	-0.07	0.19	-0.08	-0.05	-0.00	-0.06	-0.02	0.40	-0.29	-0.05	0.00	0.00
	max	-0.19	0.48	0.08	-0.05	-0.01	-0.03	-0.02	0.39	-0.30	-0.12	-0.14	0.01
res	min	-0.12	0.30	-0.06	-0.04	-0.00	-0.05	-0.02	0.40	-0.30	-0.08	-0.05	0.00
	max	-0.12	0.31	-0.07	-0.05	-0.00	-0.05	-0.02	0.40	-0.30	-0.08	-0.05	0.00
h^g	min	-0.09	0.24	-0.05	-0.05	-0.00	-0.05	-0.01	0.40	-0.29	-0.06	-0.05	0.00
	max	-0.26	0.65	-0.18	-0.02	-0.00	-0.05	-0.04	0.40	-0.31	-0.13	-0.05	0.00
α_1	min	0.04	-0.08	-0.05	-0.05	-0.00	-0.04	-0.02	0.40	-0.30	-0.08	-0.05	-0.00
	max	-0.28	0.67	-0.08	-0.04	-0.00	-0.06	-0.02	0.40	-0.30	-0.08	-0.05	0.00
α_2	min	-0.12	0.30	-0.06	-0.04	-0.00	-0.05	-0.02	0.40	-0.30	-0.08	-0.05	0.00
	max	-0.12	0.30	-0.07	-0.05	0.00	-0.05	-0.02	0.40	-0.30	-0.08	-0.05	0.00
ν_1	min	-0.12	0.30	-0.06	-0.04	-0.00	-0.05	-0.02	0.40	-0.30	-0.07	-0.05	0.00
	max	-0.10	0.30	-0.07	-0.05	-0.00	-0.06	-0.02	0.40	-0.30	-0.09	-0.06	0.00
ν_2	min	-0.12	0.30	-0.01	-0.00	-0.00	-0.01	-0.02	0.40	-0.28	-0.08	0.00	0.00
	max	-0.12	0.30	-0.10	-0.08	-0.00	-0.08	-0.02	0.40	-0.31	-0.08	-0.08	0.00
ν_3	min	-0.12	0.30	-0.07	0.02	-0.00	-0.05	-0.02	0.40	-0.29	-0.03	-0.05	0.00
	max	-0.12	0.30	-0.07	-0.12	-0.00	-0.05	-0.02	0.40	-0.31	-0.12	-0.05	0.00
ν_4	min	-0.12	0.30	-0.07	-0.05	-0.00	-0.05	-0.02	0.40	-0.30	-0.08	-0.05	0.00
	max	-0.12	0.30	-0.06	-0.04	-0.00	-0.05	-0.02	0.40	-0.30	-0.08	-0.05	0.00
π_e	min	-0.13	0.30	-0.02	-0.01	0.00	-0.01	-0.02	0.40	-0.01	-0.00	-0.00	0.00
	max	-0.10	0.30	-0.17	-0.14	-0.00	-0.14	-0.02	0.40	-0.99	-0.25	-0.16	0.00
λ^l	min	-0.12	0.30	-0.07	-0.05	0.00	-0.05	-0.02	0.40	-0.30	-0.08	-0.05	0.00
	max	-0.12	0.30	-0.06	-0.04	-0.00	-0.05	-0.02	0.39	-0.29	-0.07	-0.05	0.00
c_0	min	-0.12	0.31	-0.07	-0.05	-0.00	-0.05	-0.02	0.40	-0.30	-0.08	-0.05	0.00
	max	-0.11	0.27	-0.05	-0.01	-0.01	-0.05	-0.01	0.38	-0.29	-0.08	-0.05	0.01
c_1	min	-0.12	0.30	-0.07	-0.05	-0.00	-0.05	-0.02	0.40	-0.30	-0.08	-0.05	0.00
	max	-0.12	0.30	-0.06	-0.04	-0.00	-0.05	-0.02	0.40	-0.30	-0.08	-0.05	0.00
β	min	-0.05	0.13	-0.03	-0.02	-0.00	-0.02	-0.01	0.40	-0.16	-0.04	-0.03	0.00
	max	-0.53	1.27	-0.13	-0.08	-0.00	-0.21	-0.08	0.40	-0.34	-0.09	-0.06	0.00
T	min	-0.07	0.16	-0.02	-0.02	-0.00	-0.03	-0.01	0.40	-0.09	-0.02	-0.01	0.00
	max	-0.22	0.57	-0.14	-0.10	-0.00	-0.10	-0.04	0.40	-0.69	-0.18	-0.11	0.00

Sources: author's compilation.

Notes: The top panel reports table shows effects of fundamentals (Z_1) on overall SDV at the baseline setting, and effects restricted to the normal (SDVN) and funding liquidity states (SDVC). Large effects highlighted. The rest of the table shows the effects of Z_1 fundamentals on SDV (Z_1 , columns) at minimum and maximum values of other fundamentals (Z_2 , rows). Effects that are significantly different from the baseline effect are highlighted.

the sovereign toward default and increases SDV effects of d and ψ .

The funding liquidity crisis parameters c_0 , c_1 and the non-strategic default λ^l cause a slight decrease in absolute effects, which follows from equation (6.1).

Generally speaking, a longer crisis duration and lower impatience (higher T and β param-

eters) increases the magnitude of effects of other parameters. This is because (i) the increase in these two parameters increases the importance of the short-term relative to the long-term⁶ and (ii) parameter effects differ more between repayment vs default in the short-term compared with the long-term.

6.3.1 Funding liquidity scenarios

To investigate parameter interaction effects further Figure 6.1 investigates the SDV effects of parameters d , ψ , $\bar{g}$, r , as in Figures 5.1 and 5.2, but with respect to crisis parameters 0 and c_1 instead of π_c (i.e. π_c is held fixed at its baseline 0.3 value).

These figures plot SDV contour lines in the debt ratio - external debt share (d - ψ) plane, with positive $\bar{g} - r$ in the left-hand plots and negative $\bar{g} - r$ in the right-hand plots. The top two rows consider $c_0 = -7$ (which represents benign external funding conditions), whereas the bottom two rows consider $c_0 = 0$ in which case international liquidity is scarce and funding crisis has a larger probability. The first and third rows assume $c_1 = 0$, so that d , ψ and res do not contribute (all sovereigns are equally affected by funding liquidity) to funding liquidity crisis determination, whereas these parameters strongly influence this probability in the second and fourth rows, where $c_1 = 10$.

The first row of subplots are set in a purely normal state. As in Figure 5.1 d is more relevant in determining SDV than ψ when $\bar{g} > r$, because capital inflows and domestic debt crisis costs largely eliminate each other's opposing effects. When $\bar{g} < r$ SDV is higher in general (see colormaps). In fact, SDV is around 0.1 as $\bar{g} - r$ decreases by 0.04 points going from left-hand to right-hand plots.

There are several fundamentals which interact to determine the effects of d and ψ and are visible in most plots.

On one hand default-triggered crises reduce the incentive to default, so that SDV decreases significantly for sovereigns with high domestically held debt levels. This is apparent in nearly all plots of Figure 6.1, as SDV contours decrease into the maximum d - minimum ψ area (bottom right corners).

Another effect is due to the trend growth - real interest rate difference. When this is positive (left-hand plots), a default reduces utility especially for high external debt, which would result in SDV contours increasing away from maximum external debt (top right corners). By contrast, when $\bar{g} < r$ (right-hand plots), then SDV increases into the maximum external debt area and predicting default at the highest external debt levels in these plots.

Similar to the $\bar{g} < r$ cases, austerity measures of bailouts also result in SDV increasing in both d and ψ . Again, this force increases SDV into the top right corners of plots and it is what leads to default predictions also in the plot 3 and 7, where otherwise trend growth and real

⁶The reason for this result is that the short-term receives a time-aggregating term with a key component of $(1 - \beta^T)/(1 - \beta)$. This component increases in both T and β within allowed ranges of these parameters.

Figure 6.1: SDV contours in allowed d, ψ ranges (funding crisis state)

Sources: author's compilation.

Notes: The figure plots SDV contour lines in the d - ψ plane for scenarios of real interest rates r and trend growth $\bar{g}$ ($\bar{g} > r$: left plots, $\bar{g} < r$: right plots), funding crisis probability parameters c_0 (set to its minimum in top four plots and maximum in bottom four plots) and c_1 . SDV levels are identified on color bars next to each subplot. The $SDV = \{-0.001, 0, +0.001\}$ contours of black dot-dash lines depict the boundary of the default decision.

interest rates would instead lead to repayment predictions. (In plots 1 and 5 this effect is not as relevant because $c_1 = 0$.)

Finally, exchange rate depreciation reduces SDV for higher ψ due to exchange rate depreciation in disorderly defaults independently of d .

The combination of the latter two (austerity, exchange rate depreciation) and the first effect (losses due to domestic debt holdings) result in the saddle shape of SDV in several plots. The highest and increasing SDV values are in the bottom left (low debt, domestic) and top right (high debt, external) corners. The lowest and decreasing SDV values are in the other two corners. For instance, in the last plot, SDV is increasing in ψ above a debt ratio of 0.3 (an effect of higher demanded austerity measures and lower domestic debt default costs) and is decreasing below that (higher private external debt shares would result in larger default-crisis output losses due to exchange rate depreciation). SDV is increasing in the debt ratio above $\psi = 0.2$ (larger demanded austerity measures) and decreasing in debt below this level (high domestic debt results in larger default output losses, which increases willingness to repay).

With these parameter settings default is usually predicted only for cases of very high external debt levels. However, in most cases SDV values lie well within the range of the political economy parameter α_2 so that this fundamental could be crucial in the default decision.

6.4 Other government policy parameters

This section deals with the optimal choice of policy parameters other than the choice of repayment or default (λ^g): I will discuss how the debt ratio (d), the external share of debt (ψ), the haircut (h^g) are chosen under various circumstances described by other parameters. These policy parameters, though not the key focus of the thesis, are interesting as fundamentals that enter the strategic default decision. Also, since the model provides implicit predictions about these parameters, contrasting these with empirical evidence evaluates the plausibility of model assumptions.

Model I predictions on the choice of these policy parameters are simple and unrealistic. Assumptions on utility imply that accumulating high external debt is beneficial if $\bar{g} > r$ (assuming that α_1 is such that $\psi + \alpha_1 > 0$). When trend growth is relatively high, the sovereign is motivated to issue maximum debt and stay in the debt contract, because this maximizes net capital inflows and hence consumption utility. In addition, all debt is assumed to be external, because this raises utility more than domestic debt. In these circumstances default is only chosen in case of a political environment hostile to investors. If default were to happen, the government would choose minimum haircut both to avoid any costs on output that a default may entail and to keep post-default debt ratio high. When, instead, $\bar{g} < r$ (or α_1 is negative: i.e. society favors fiscal prudence) debt is chosen to be minimal, domestic instead of external debt would be preferred and maximum haircut would be chosen in case of default. Therefore Model I would explain variation in d and ψ with variation in trend growth vs real interest rates.

A key shortcoming of Model I, though, is that it cannot account for large domestic debt stocks seen in large parts of the emerging and advanced world: debt is either chosen to be zero (small and domestic) or it is chosen to be fully external (large and external).

Model II addresses this shortcoming. There are several important features in Model II that

change debt optimization and which allow higher domestic debt stocks to be accumulated. The first is the possibility that defaulting on debt could result in a currency crisis that threatens to reduce output in countries with high ψ (assumed to proxy high level of financial dollarization). This would, by itself, not deter high external debt accumulation, because the sovereign could simply run up external debt without any intention to default. However, Model II also incorporates a funding liquidity crisis, which has a higher probability of occurring in countries with high external debt and in which accidental, large-cost disorderly defaults can occur. Even if disorderly non-strategic defaults are perceived as low probability events, sufficiently high output losses in such cases (either due to high domestic debt holdings or high financial dollarization) would result in government considering lower and more domestically financed debt levels would be optimal.

6.4.1 Effect of crisis parameters

First, I analyze the case when all parameters in the model are set to the baseline, except for policy parameters (d , ψ , h) and parameters that determine the funding liquidity crisis probability, c_0 and c_1 .

Figure 6.2: Value functions in Model II at different d , ψ , c_1 and c_0 levels

Sources: author's compilation.

Notes: Each subplot in the figure shows value functions for repayment (solid lines) and default states (dashed lines) for the domestic and external debt only cases ($\psi = 0$: blue; $\psi = 1$: red) at given levels of debt (x-axis) and funding liquidity crisis parameters (subplots). All other parameters are set to the baseline.

Figure 6.2 shows value functions of repayment (VR) and strategic default (VD) for minimum and maximum external shares of debt at various debt ratios (x-axis). When the probability of funding crisis is negligible (top left plot), repayment values significantly exceed default values at all d and ψ levels, so default is not chosen and investors are willing to lend at any policy

choices. Utility in repayment is also increasing in both d and ψ , which predicts that the government chooses high debt levels and finances it in external bond markets (as in Model I). Domestic debt choice has a flatter repayment value function so increasing the debt level adds less utility when debt is domestic rather than external.

Debt optimization changes significantly when funding liquidity crises are possible. The top right subplot refers to a case, when funding crisis probability is highly dependent on external debt levels. Since central banks in many cases could provide temporary funds for governments as a last resort, whereas foreign exchange funding is more difficult (subject to reserves and international bailout), such a scenario has practical merits. In this case, too, repayment is preferred by the government for all (domestic and external) debt levels. However, unlike in the previous case, at higher debt levels domestic debt is favored, because external debt entails a funding crisis risk and this has several disutilities: output loss due to exchange rate depreciation and austerity measures in repayment and added output losses in case of an unwanted non-strategic default. Because $c_0 = 0$ domestic debt avoids the funding crisis and the slope of the repayment value function is monotonously increasing in debt as before. For debt ratios up to around 70 percent external debt issuance provides higher benefit, but above this level domestic debt is preferred. The global optimum is for the government to issue maximum domestic debt.

The third (bottom left) subplot examines the case, when funding liquidity crises are possible, but are not tied to external debt stocks. This could identify cases when, for instance, international liquidity conditions or global risk appetite for sovereign debt evaporates in general. In this case, too, domestic debt with repayment is preferred, because external debt entails larger costs due to foreign currency depreciation (with resulting financial sector problems and austerity demands by international creditors). However the large c_0 in this case does not guarantee domestic debt to avoid funding crisis. If funding crisis materializes, then governments with higher domestic debt levels suffer larger austerity measures and output loss due to bond valuations. The optimum in this case is having minimum, domestically financed debt.

The final subplot has implications which combine characteristics of the last two cases.

6.5 Political economy feedbacks when funding crisis is possible

This section adds a hypothetical discussion about the implications of potential endogeneity of the political economy parameter α_2 , which denotes an unconditional utility/disutility for defaulting on debt (in case of a default α_2 is added to current utility). The parameter has an additional, indirect effect on utility: when α_2 is negative, this lowers SDV and, through that, the cost of funding.

The chapter considered so far a case in which α_2 is a general voter utility parameter exogenous for the government and political parties. Political parties are interested in inferring the public opinion about α_2 and earning votes by promising (or in case of the governing party: ex-

ecuting) actions that are consistent with utility maximization and therefore including α_2 in their calculations about repayment and default.⁷

This section discusses the case in which government and political parties may have some discretion over these parameters. For example, the government could influence what the media broadcasts/publishes and as such it may influence public opinion. If the government is inclined to use these channels and these channels are efficient in steering public opinion, then the government can include α_2 in the policy parameter set.

As argued before, when the probability of crisis is low and parameters are near baseline values the government is interested in maximizing the level of external debt. In this benign setting default is not a relevant policy choice, because the government is interested in a continuous inflow of funds that is consistent with keeping a stable debt ratio. In this case, the government could optimize by lowering α_2 to its minimum level, because this lowers credit risk perception. Rates are fixed in the model, but thinking hypothetically outside of this framework, lower perceived credit risk would lower r . Then, utility increases through a higher value of the difference between trend growth and real interest rates, $\bar{g} - r$.⁸

However, as the probability of funding liquidity crisis increases, the chance of a default increases irrespective of government policy choice. This results in the (strategic) repayment value function now incorporating an element increasing in α_2 , because a default may occur even when the government is willing to repay.

On the other hand, investors could take the choice of α_2 into account when pricing debt and charge higher credit spreads for countries, where this parameter is perceived to be high.⁹ The optimum choice of the parameter α_2 , then has two opposing determinants for a rational government: the possibility of a liquidity-default would call for the maximum α_2 value, whereas the effect on real interest rates would call for the minimum α_2 value. The more probable (π_C , λ^l) and persistent (T and β) a liquidity crisis and default is expected to be and the less effect α_2 has on interest rates, the more likely is that the maximum α_2 would be chosen.

This becomes even more important, when SDV is close to zero and the relative effect of

⁷Individual preferences are likely to be heterogenous about government default, which may induce different political factions to also take up different positions on the issue once default becomes a relevant issue in public thought. It is also likely that political platforms built on promoting market institutions, investor rights, integration with the international community would be biased toward repayment and platforms critical of market efficiency and institutions and hostile toward the (international or domestic financier) investor community would be tilted towards defaulting. In these cases, too, α_2 would be exogenously rather than endogenously determined, but it would be the political platform that determines this value. Such a framework may be adapted to analyze how shifts in utility of voters promotes the popularity of different political platforms that eventually seep into governing decisions with a lag. Rather than explicitly modelling political competition, I keep the focus on a single political governing party that however needs to take into account how social preferences change to remain in power.

⁸Naturally, the credibility of government being committed to low values of α_2 is important. If α_2 can be influenced, the stability of the governing political platform with respect to market institutions, property rights, international integrations are key in this regard. If, in contrast, the government can be assumed to opportunistically and quickly change its political stance on these issues or if there is a risk that the government will be replaced by another political faction with significantly different motives (e.g in upcoming elections or if there is high probability of civil unrest, coups, revolutions), then commitment to low α_2 is not credible and would have less effect on r .

⁹A formal treatment of interest determination and these effects is the subject of the next section.

the political economy parameter α_2 increases. If the government is committed to repayment or social preferences are tilted into this direction and are not likely to change as a result of the crisis (as could be plausibly assumed in developed markets with strong market institutions), then a substantial negative α_2 component may counter the effects of other parameters on an increasing SDV and could be an important factor that anchors credit spreads even in these circumstances. This effect could explain increasing sensitivity to political-institutional factors in the cross-section of credit risk indicators in global funding liquidity crises, because in these times SDV increases everywhere and cross-section variation in the α_2 parameter becomes more relevant in differences in probability of default.

Dynamics are suppressed in this model and I am not going into more detail here, but I will highlight that possible adjustment of α_2 could result in a nexus between the political economy parameters and interest rates, which could lead up to default through a self-fulfilling liquidity crisis. If the parameter significantly affects default probability, then expectations of an increased α_2 may cause interest rates to rise on increased credit risk. This would then raise the perceived probability of a funding liquidity crisis and default making the government interested in shifting α_2 upward. An adverse feedback loop could thus develop as investors lose confidence in the creditworthiness of the country and the government becoming more hostile towards investors and debt repayment. If this nexus is known and the eventual strategic default is anticipated by market actors, then credit is withdrawn before a default and this already triggers the funding liquidity crisis scenario.

Note, that this case involves a nexus between interest rates and the political economy stance toward repayment (market institutions), rather than interest rates and fiscal variables as in other models of self-fulfilling defaults (Calvo, 1988; Cole and Kehoe, 2000; Bernardo, 2016). A more formal elaboration of this subject necessitates assumptions on interest rate determination and dynamics, which is the model in Appendix C.2.

6.6 Model implications

The last two chapters studied models that differ from the mainstream sovereign literature in that they incorporate (i) domestic debt next to external bond issuances; (ii) the possibility of a funding crisis in which the government is at risk of a non-strategic default even if it turns to international assistance; and (iii) political economy factors that may affect the borrowing and default decision.

These are important aspects of sovereign debt and their omission may hinder a proper analysis. Domestic debt constitutes a larger share of issuances in both emerging and advanced markets than external debt. Funding crises are prevalent and governments occasionally face the threat of defaulting even in cases when they seem to be willing to repay obligations. Debt repudiation usually materializes by governments with a strong anti-investor populist government rhetoric, whereas repudiation is not characteristic in developed countries with long-standing institutions

that protect investor property rights.

The results of the chapters suggest that these characteristics importantly influence borrowing and default decisions. Domestic debt acts as a commitment device for sovereign contracts, because governments may plausibly fear that defaulting on domestic debt could hurt the domestic financial sector and, through that, domestic consumption. Such cost of defaults causes investors to be willing to hold substantial domestic debt amounts. The models here assume that domestic debt issuance is also beneficial for the government, because median voters are more impatient than investors and thus net borrowing increases utility. Moreover domestic bonds may be preferred over external (foreign currency) debt issuances, because of the possibility of funding liquidity crises. Funding liquidity crises are argued to be more probable in countries that issue bonds abroad in foreign currency, because central bank help with foreign currency funding needs is limited by the size of currency reserves. Austerity measure conditionality of international assistance and possible non-strategic defaults within a funding crises also motivate governments to issue domestically.

Related to the subject matter of the thesis, these characteristics of sovereign issuance could also be important in explaining why the sensitivity of sovereign debt prices to fundamentals changes over time and within crises, in particular.

- In contrast to an uncontested result in the theoretical literature since [Eaton and Gersovitz \(1981\)](#) that the motivation to default increases with the debt-to-output level, I showed both analytically and numerically (calibrating parameters to emerging market and developed country data) that the sign of the debt ratio effect is ambiguous and depends on several other factors. Higher debt decreases spreads when trend growth is high compared to real interest rates, but increases it when trend growth is lower. Higher debt decreases spreads when debt is domestic and the probability and depth of a default-triggered crisis is large. Higher debt increases spreads when debt is foreign-currency denominated and there is a large probability of a funding liquidity crisis.
- In this framework output fluctuations (even of crisis proportions) play a small role in the default decision. However, if output fluctuations have a bearing on trend growth expectations, which is a significant factor of the default decision, they could be highly important drivers of sovereign spreads. These results are in line with popular quantitative sovereign debt models (e.g. [Aguiar and Gopinath, 2006](#), and a line of research since).
- Current account and fiscal balances in these models were restricted to be consistent with a stable structural debt ratio. These balances tend to be countercyclical due to this restriction, worsening when trend growth improves and improving when trend growth declines. This is in line with emerging market experiences. Because trend growth improvements lower the motivation to default, the model predicts that sovereign spreads decline when current account and fiscal balance deficits deteriorate. This contradicts what one would

expect based on an ability to pay perspective for defaults, i.e that spreads would decline when balances improve. Empirical literature results concerning the effect of the current account on spreads have been particularly ambiguous as shown in Chapter 4 and this may be a reason. The empirical literature more consistently found fiscal deficits (rather than surpluses) to be associated with higher spreads.

- Official reserves are predicted to play a limited role in sovereign debt pricing, but could significantly reduce the chance of a funding crisis in times when external liquidity conditions worsen.
- The vulnerability of the banking system could play an important role. The models in this chapter predict that larger financial deepening decreases the willingness to default. This is consistent with the observation of low spreads in developed markets that have large financial sectors and domestic government securities markets. However the models also predict, contrasting empirical literature evidence, that more vulnerable banking sectors increase the motivation to repay, because transmission of default-induced losses to the economy would be larger.
- The political economy variable that represents a preference for debt repayment vs default, which is likely to be highly correlated with strength of market institutions, may often have a decisive impact. This factor becomes especially relevant when there is a low perceived output cost of a crisis (debt is low, foreign-held, is not perceived to affect the financial sector; or default experiences elsewhere have been benign) and it is also predicted to have larger relative impact in financial crises (when the scale of SDV is smaller). In contrast, a significant chance of a default-triggered crisis deters even politically-motivated sovereign defaults and thus reduces the significance of this factor.

The models proposed in the chapters also support a much simpler explanation for observed changes in fundamental effects on spreads. Within the model framework fundamental effects on SDV are approximately linear. However, linear fundamental effects on SDV translate into non-linear effects on spreads when there is uncertainty regarding SDV (e.g SDV is normally distributed about its expectation).¹⁰ As the expected value of SDV nears zero from below marginal increases in SDV causes the probability of default to climb at a faster pace, because the probability density function is increasing in this region. This implies that all fundamental effects on spreads become larger in countries and time periods, in which the probability of default is higher. It also implies that the modelling approach of using logarithmic spreads (as the emerging

¹⁰In the current model we considered values of fundamentals and other model parameters within their empirical/theoretical ranges and thought of these values to be fixed in time. However thinking hypothetically at an extension of this framework, there is naturally a lot of uncertainty around these parameters and even in the observed values of fundamentals due to reporting lags for instance. Moreover if bonds were longer dated and fundamentals could change in the period until the repayment decision this can also add uncertainty to fundamentals. All this translates into uncertainty around (currently estimated value of) SDV, which changes the binary default decision into a probability of the default decision.

market sovereign literature that follows the tradition of [Edwards, 1983](#), does) will have more robust estimation results than models using linear interest rate differences (as common in the eurozone sovereign literature).

There are important limitations of the models considered in the two chapters. First, interest rates are set exogenously, whereas investors are likely to react to changes in the willingness to repay, the probability of funding liquidity induced defaults and also, global liquidity conditions. Second, a fixed (structural) debt ratio is assumed. Third, dynamics are much simplified as basically a two-period model is considered (a short-term and a long-term). Fourth, stochastics are limited to realization of only four states of nature. Other restrictions such as assuming an endowment economy, abstracting from capital formation, monetary phenomena may also be important, but are shared with the bulk of the sovereign literature.

In Appendix [C.2](#) I present a model that endogenizes interest rates, allows gradual changes in the debt ratio and adds a few more dynamic and stochastic elements to this model and still leads to very similar results.

CHAPTER 7

Hypotheses

The thesis investigates three hypotheses.

The first two hypotheses consider the general claim of the empirical literature that the role of country fundamentals is time-varying in sovereign credit risk pricing.

In the thesis I focus on the cross-sectional (pricing) effect of fundamentals on sovereign spreads. These cross-sectional effects show the spread increments that investors demand for holding sovereign bonds and long CDS positions of worse credit quality due to fundamentals. I assess time-variance in both the linear and the logarithmic sovereign credit spreads specifications, i.e time-variation in the basis point and percentage pricing effects of fundamentals on spreads. Following most practitioners as well as several academic papers, I initially use sovereign credit ratings to proxy domestic fundamentals. As reviewed before, ratings have several important benefits for modeling fundamentals: they are independent of risk premia, they aggregate several important and distinct aspects of country fundamentals and the rating scale successfully captures increased occurrences of future credit events. On the other hand ratings also have several drawbacks: they are lagged, overly persistent and coarse measures of fundamental credit risk that focus on long-term trends and tend to ignore fluctuations in credit risk due to the business cycle. To treat these problems I test the hypotheses controlling for rating trends and business cycle effects. Other than ratings, I also use several specifications that include explicit macroeconomic and political-institutional variables relying on both the empirical literature summarized in Chapter 4 and the theoretical models in the last two chapters.

Much of the literature dealing with time-variation in fundamental effects has found time-variation, which would favor setting up the null hypotheses stating time-variance. However, the bulk of the sovereign credit risk literature still assumes time-homogeneity, which would suggest the opposite. Since F-tests and coefficient stability tests are traditionally set up with the null of no structural change, this is also favored here.

Hypothesis 1a. *(Fundamental effects) The pricing effect of country fundamentals in sovereign credit spreads is stable in time.*

Hypothesis 1b. *(Fundamental effects) The pricing effect of country fundamentals in the logarithm of sovereign credit spreads is stable in time.*

The second hypothesis considers the time-homogeneity of the variance share attributed of fundamentals. Testing the hypotheses uses ratings as well as a number of other fundamental proxies commonly used in the literature and again focuses on the cross-sectional variation in levels of sovereign spreads. Only the logarithmic specification is considered.

Hypothesis 2. *(Fundamental variance explained) The variance share attributable to country fundamentals in the cross-sectional variance of log sovereign credit spreads is stable in time.*

The third hypothesis is concerned with the claim in the empirical sovereign credit risk literature that the crisis in the eurozone periphery, and specifically Greece, in 2010-2012 has led investors to reprice the importance of the debt ratio in credit risk assessment. The explanation commonly provided is the so-called 'wake-up call hypothesis', which claims that in crises investors reprice fundamentals more generally based on the observed relative weaknesses of the country at the epicenter of the crisis. I test the claim of time-variance of the debt ratio on a number of model specifications that use different controls for other, potentially confounding fundamental factors. I use the logarithmic functional form for the sovereign spread dependent variable.

Hypothesis 3. *(Debt ratio wake-up call) The pricing effect of the government debt-to-GDP ratio in the logarithm of sovereign credit spreads has increased in the sovereign crisis of 2010-2012.*

PART III

Empirical analysis

CHAPTER 8

Preliminary empirical analysis

The goal of this chapter is to study the properties of ratings and sovereign credit spreads and their relationship to establish plausible empirical model specifications to use in the empirical analysis. The chapter first reviews basic stylized facts of credit ratings and specifies the functional form that best seems to link ratings to default probabilities. Linking ratings to default probabilities is useful to link default probabilities to Strategic Default Value of Chapter 5 and 6 facilitating the empirical application and testing of the models therein. The second part of the chapter links sovereign credit spreads (CDS spreads and bond spreads) to ratings and so establishes the link of spreads with default probabilities and SDV.

As discussed in the literature (see Chapter 3) ratings are slow-moving, involve persistent trends and tend to overlook cyclical components of default risk, therefore they are a noisy assessment of default risk. Credit spreads are more timely, but include a risk premium component next to the component of default risk making these indicators noisy proxies of default risk as well.

8.1 Credit ratings vs the probability of default

As reviewed in Chapter 3, rating notches (of long-term issuer foreign currency obligations) have rather vague definitions. They are not directly tied to expected cumulative default probabilities or other actuarial concepts. Nonetheless, the definitions still reveal that the difference between rating notches represent different perceived default probabilities on the long-run and rating agencies provide historical default frequencies and rating transition matrices that help in quantifying the relationship.

For the purposes of the thesis it is useful to come up with a proper quantitative relationship that links ratings and default probabilities, because ratings can then be used to decompose credit spreads into default risk and risk premium components. A similar exercise has been done by [Remolona, Scatigna and Wu \(2007\)](#), who identified a measure they named rating-implied expected loss. The methodology followed here is similar, but it also takes into account of the dynamic properties of ratings.

8.1.1 Some stylized facts of credit ratings

I primarily rely on a panel data set of ratings compiled for the thesis and described in the Appendix A.1. In particular I use ratings of three major agencies on 107 sovereigns that were available from Jan 1992 to Nov 2017. In the thesis references to a single rating per country

Figure 8.1: Time series of ratings

Sources: author's compilation.

Notes: Rating time series. Red dots are ratings of developed countries, blue are those of emerging markets. Means of each group are emphasized.

and time period denotes the averages of the available ratings across agencies.¹ In regressions with spreads and other quantitative analysis, where continuous measure is needed I use the usual linear transformation of ratings (AAA/Aaa: 1, AA+/Aa1: 2, AA/Aa2: 3, ...).

Appendix Table A.1 lists descriptive properties of ratings. The table suggests that credit ratings are largely comparable across agencies. Moreover ratings are very persistent. Pooling all observations of a daily (weekdays) dataset reveals that ratings have changed on average only every 2500-3300 days in the sample, so roughly every ten years. Some of this results from the sample being biased towards developed countries (agencies rated mostly developed countries and only the largest Latin American ones in much of the 90's).

Using these two facts (large persistence and comparability of ratings), we can increase the frequency of rating changes by averaging ratings across agencies. This lowers the duration of periods without rating changes to around 1000 days and is likely to reduce some of the subjectivity in ratings by any individual agency teams.

Unlike sovereign spreads and other financial indicators, rating time series of individual

¹The literature (see Chapter 3) finds differences across agency reaction functions, but their rating scales are largely comparable.

sovereigns are not strongly correlated. There is a high dispersion in the cross-section, whereas time series variation is small. As seen in Figure 8.1, the cross-section means of ratings displayed a slight downward tendency prior to the crisis (an improvement) especially in the case of emerging markets. After the crisis, the cross-section mean of ratings increased again, driven by an increase of developed country ratings.

8.1.2 Functional form

There is no theoretical reason why rating scales should be linked to cumulative default frequencies by a linear, logarithmic, logistic or any other functional form. Therefore deriving such a link must be empirical in nature. Different time samples would probably yield different precise links between ratings and default probabilities,² although definitions of rating scales does not change and therefore individual rating grades should largely denote the same default probabilities, which makes ratings comparable over time. Long historical data can be used to calculate rating transitions and default probabilities and shorter windows of ratings data can be used to estimate some time-variation in these quantities, as done in a subsequent subsection of this chapter.

I rely on both the ratings data set used throughout the thesis (which allows a direct way of calculating cumulative default frequencies) and additionally, in this section, I also make use of rating transition matrices published by the three credit agencies [Moody's \(2017\)](#), [Standard & Poors' \(2018\)](#) and [Fitch Ratings \(2016\)](#). The rating transition matrices and one-year ahead default probabilities by rating notches can be iterated forward to recover 5-year survival rates and 5-year cumulative default probabilities for rating notches.³ For Moody's I have access to only letter grade ratings, but for Standard & Poor's and Fitch Ratings these are available on the finer grid of letter modifiers (e.g. BB-, BB, BB+). I also use cumulative corporate default probabilities reported by Standard and Poor's for presentation purposes in this section.⁴

I proceed with fitting three regression models. The first is a standard linear regression estimated by OLS that regresses default frequencies on a linear scale of ratings (*RAT*: which increases from 1: AAA to 18: CCC). The second is also a linear regression, but one in which the dependent is the logarithmic transformation of default frequencies.

The third model is a generalized linear regression model with a logistic link function, i.e.

²In the corporate arena, such transition matrix drifts are routinely calculated, but this is not done for sovereigns due to the infrequency of rating changes and the small number of sovereign issuers.

³The choice of the 5-year horizon is somewhat ad hoc, though it can be rationalized by this horizon being close to central tendencies of the distribution of bond maturities and therefore agencies therefore should target this horizon so that their ratings are most informative for bond investors. Also, the 5-year is the most liquid maturity of the CDS market as well.

⁴The rating data set used in the thesis allows a direct observation of cumulative default frequencies, but the published rating transition matrices also has the relative advantage that it is based on more ratings data (longer histories and more countries) than the panel data set I have collected. Transition matrices of both the published sources and the ratings data set allow calculation of cumulative default frequencies. The transition matrix publications are available for the longest histories and most recent cohorts, but are not published for interim time periods. An advantage of the rating data set is that default probabilities can be calculated for any subsets of the time sample.

Table 8.1: Logistic regressions of default probability on ratings

Regr. spec	(A) TR MAT-based		(B) Panel data R-AVG		(C) Panel data Moody's		(D) Panel data S&P		(E) Panel data Fitch	
Dependent	<i>logodds5y</i>		<i>logodds5y</i>		<i>logodds5y</i>		<i>logodds5y</i>		<i>logodds5y</i>	
Regressors	coef.	s.e.	coef.	s.e.	coef.	s.e.	coef.	s.e.	coef.	s.e.
constant	-10.424***	(2.731)	-10.138***	(2.420)	-9.468***	(2.359)	-7.397***	(2.042)	-7.708***	(2.642)
RATING avg	0.591***	(0.188)	0.586***	(0.165)						
RATING Moody's					0.556***	(0.162)				
RATING S&P							0.371**	(0.152)		
RATING Fitch									0.394**	(0.194)
χ^2 vs null model	21.80		28.80		29.30		10.50		7.90	
p-val	0.000		0.000		0.000		0.001		0.005	
log LR	0.614		0.521		0.537		0.310		0.351	
BIC	19.378		32.313		30.998		28.975		20.146	
No. observations	18		18		18		17		16	

Sources: author calculations.

Notes: Logit regressions of the log-odds of default on ratings. The specification (A) uses CDF calculations based on published transition matrices, (B) uses direct observations of default for ratings averaged across agencies, (C)-(E) specifications use direct observations of default for individual agency ratings.

one which assumes that the log odds is related linearly to the rating scale:

$$\log \frac{\lambda_j}{1 - \lambda_j} = a + bRAT_j + u_j, \quad (8.1)$$

where λ_j are the (theoretical) five-year cumulative default probabilities at rating notch j , and a , b are population parameters that are intercept and rating sensitivity of the log-odds of defaulting and u_j is a disturbance term expressing the fact that ratings are an imperfect measure of default probability.⁵ Estimation of $\hat{a}$ and $\hat{b}$ in this case proceeds by maximum likelihood with the likelihood based on the binomial distribution. To better describe the uncertainty around point estimates, total observations for each rating notch are calibrated to the panel data set (e.g. the number of non-overlapping five-year windows starting with AAA, AA+, AA notches and so on). In the panel data set, roughly 30 observations are available for the best rating notch and 5-15 for other notches.⁶ The longer time series available for agencies would add more observations and would result in narrower confidence bounds. On the other hand, these models assume independent observations, however the persistence of rating changes and thus serial dependence within transitions would work the other way.

Table 8.1 provides regression output. As a rule of thumb these regressions tell us that each rating notch worsening increases the log-odds (of defaulting within 5 years) by around 0.5-0.6 units ($\hat{b}$) indicating a 60-80 percent increase in the default probability ($\exp(0.55) = 1.73$) with the risk-free (below triple A) rating ($\hat{a}$) being associated with log-odds around -7 to -10 (0.001% – 0.1% probability of default).

Figure 8.2 plots calculate 5-year cumulative default frequencies based on the rating data set,

⁵Inverting the logistic link yields the default probability $\lambda_j = 1/(1 + \exp(-a - bRAT_j - u_j))$.

⁶Using default frequencies based on rating transition matrices, but the number of observations based on actually observed ratings is consistent with the view that the default set observed in the data (e.g. from the 1980s to 2017) is only one possible realization of the true data generating process. If many alternative worlds could have been observed, then (based on rating transitions, which are more frequent) there would have been defaults observed with low probability for even high grade issuers. This is the rationale of using defaults based on rating transitions. The rationale for still using the observation numbers of rating notches within the historical panel data set is to identify the uncertainty of the estimates due to the fact that we only have 30-40 years of data and thus rating transitions and default frequency calculations are imprecise.

Figure 8.2: Rating grades and 5-year cumulative default probabilities

Sources: author's compilation.

Notes: Plots display the relationship between 5-year cumulative default frequencies (y-axis) and rating notches (x-axis). The plots also display regression point estimates and 95 percent confidence bounds for logistic fit (left-hand plots), logarithmic regression fit (middle plots) and linear regression fit (right-hand plots). The top panel has linear y-axis scale, whereas the bottom panel has logarithmic y-axis scale.

the published agency transition matrices and the regression fit based on the rating data set.

The figure suggests that the relationship between ratings and the probability of default is best characterized by a logistic relationship (left-hand plots), a finding consistent with other studies in the literature. The linear fit does not capture the exponential increase in probabilities at the high-risk end of the rating scale and does not respect the positivity of default probabilities at the low-risk end (middle plots). The logarithmic fit is much better than the linear specification, however its confidence intervals would run into implausible predictions of larger than unit default probabilities at the high-risk end of the rating scale (right-hand plots).

The figure (and regression) also shows that the cumulative default frequencies of the three agencies, while not identical, are reasonably close to each other and they lie within the confidence intervals of the logistic model. Corporate default frequencies of similar ratings appear to be higher compared to sovereign probabilities.

Ratings vs SDV

With additional assumptions, the logistic regression parameters can be related to SDV, the relative value of default in the theoretical models of Chapter 5. If the sovereign default depends on the willingness to repay aspect only, then by Definition 5.2 default occurs if – within the time to maturity of the asset – SDV exceeds 0.

Since the future SDV is not known with certainty (and there may also be uncertainty surrounding current SDV), the current estimate of SDV ($E_t[SDV_t]$) acts analogously to a distance to default metric in a structural credit risk model.

To explore this further suppose that default may only occur once, at the time to maturity (e.g. that is when the sovereign decides whether to repay its debt). Also, suppose that SDV is a random walk with a global and an idiosyncratic innovation component, both of which are Gaussian. In particular suppose the dynamics of SDV is given by:

$$dSDV_{i,t} = \beta_i \sigma_g W_t^g + \sigma_i W_t^i,$$

with W_t^g, W_t^i Wiener processes and β_i a country-specific sensitivity to global shocks affecting SDV.

Suppose that there is also uncertainty (for investors) about the current state of SDV: $SDV_t = E_t[SDV_{i,t}] + \xi_i$, with $\xi \sim N(0, Var[\xi_i])$.

Then,

$$SDV_{i,t+\tau} = E_t[SDV_{i,t}] + \xi_i + \sqrt{\tau} \beta_i \sigma_g W_t^g + \sqrt{\tau} \sigma_i W_t^i.$$

Since the stochastic terms are sums of independent normal variables, the distribution of $SDV_{i,t+\tau}$ is normal with mean $E_t[SDV_{i,t}]$ and variance $Var[\xi_i] + \tau(\beta_i^2 \sigma_g^2 + \sigma_i^2)$. From this, the probability of default is

$$\begin{aligned} \lambda_{i,t+\tau} &= Prob[SDV_{i,t+\tau} < 0] = 1 - Prob[SDV_{i,t+\tau} > 0] \\ &= 1 - \Phi \left(\frac{-E_t[SDV_{i,t}]}{\sqrt{Var[\xi_i] + \tau(\beta_i^2 \sigma_g^2 + \sigma_i^2)}} \right) \\ &= \Phi \left(\frac{E_t[SDV_{i,t}]}{\sqrt{Var[\xi_i] + \tau(\beta_i^2 \sigma_g^2 + \sigma_i^2)}} \right). \end{aligned}$$

If we approximate this normal distribution with a logistic distribution of the same mean and variance⁷, then we can use the quantile formula of the logistic distribution $Q(p; \mu, s) = \mu + s \log p / (1 - p)$ with scale $s = \sqrt{3} / \pi \sigma$, to get an expression for the log-odds of default in terms of the current expectation of SDV and stochastic terms relating to uncertainty and its future dynamics:

$$\log \frac{\lambda_{i,t+\tau}}{1 - \lambda_{i,t+\tau}} = \frac{E_t[SDV_{i,t}]}{s}, \quad s = \frac{\sqrt{3}}{\pi} \sqrt{Var[\xi_i] + \tau(\beta_i^2 \sigma_g^2 + \sigma_i^2)}.$$

Default probability increases when the current expectation of SDV increases, or when the scale of the distribution increases (since current SDV is negative this increases toward zero). The

⁷The normal and logistic distributions are similarly shaped, although the logistic distribution has higher kurtosis.

scale increasing means that current expectation of SDV becomes a less reliable measure of future SDV. The scale could increase via the uncertainty around current SDV (noise in its measurement, e.g. due to political uncertainty) or by uncertainty about its future dynamics increasing, which itself may be caused by a longer time to maturity or larger volatility of the idiosyncratic or global shocks, or larger sensitivity to global shocks.

Using equation (8.1) we can relate SDV to ratings:

$$E_t[SDV_{i,t}] = (a + bRAT_{i,t} + u_{i,t})s. \quad (8.2)$$

Therefore the logistic link between ratings and default probability implies a linear functional form between SDV and ratings given the above assumptions on the dynamics of SDV.

8.1.3 Accounting for rating persistence

Time series models of ratings

As reviewed in Chapter 3 ratings have been characterized by persistence in both their levels and their dynamics. Ratings are fairly stable in general and when they are changed individual issuers typically experience longer trends in upgrades or downgrades. Partly this may be due to true underlying trends in news on fundamentals, as agencies are careful to only book changes in creditworthiness, which are perceived to persist on the longer run. The literature has also found evidence of ratings being lagged compared to the market.

If future credit rating changes can be predicted from knowledge of current and past ratings, then investors who price the probability of default throughout the life of a bond or CDS contract need to consider the expected change of future ratings (and the associated hazard rate) rather than just look at current ratings and the cumulative default frequency it implies.

To account for this factor, I explore how the relationship previously recovered between ratings and default probabilities by the logistic regression need to be adjusted. To do this, I regress all pooled rating changes on a constant and last period rating levels (to account for possible mean reversion) as well as lagged rating changes (to account for persistent dynamics):

$$\Delta^t RAT_{t,i} = a_0 + a_1 RAT_{t-h,i} + \sum_{s=1}^{s_{max}} b_s \Delta RAT_{t-hs,i} + u_{t,i}, \quad (8.3)$$

where i is cross-section unit (all units are used for which data are available), t is the current time period, s is the cursor of lags and h is the time period steps that are considered in right-hand variables. For instance with monthly data and $h = 3$, the monthly rating changes (Δ^t) are regressed on three-monthly (i.e. quarterly) changes of past ratings (s_{max} of these) and a three-monthly (quarterly) lag of the rating level.

Several versions of this regression are estimated on quarterly as well as monthly data frequencies. Figure 8.3 shows the Bayesian Information Criterion for some of these specifications.

Figure 8.3: Rating change persistence and mean reversion

Sources: author's compilation.

Notes: Plots display Bayesian Information Criteria (y-axis) of model specifications with or without rating level lags and different lags of rating changes (x-axis). The specifications with 'dRAT(1)' only include one rating change lag (at various horizons), whereas specifications with 'dRAT(n)' include all rating change lags up to n, the lag displayed on the x-axis. Models with lower BIC are preferable to ones with higher BIC.

Compared to a constant only specification (and basically a random walk as the constant is not significantly different from zero) adding lagged rating only slightly improves the information criterion (lowers BIC), which suggests that ratings are near unit root processes and mean reversion is not an important factor determining dynamics.

Persistence in rating changes (i.e rating trends) appears to be more important. Judging based on BIC of specifications with single rating change lags (blue lines) the first lag is the most important in quarterly data and the second lag is most important on monthly data. The long specifications (black lines) that include more rating change lags have the lowest BIC around four maximum lags on both quarterly and monthly data. When the rating lag steps (h) are increased, this improves parsimony and lowers BIC for monthly data frequencies: i.e lowest BIC are found when the specification has a single four-monthly rating change lag ($h = 4, s_{max} = 1$). In the case of quarterly frequencies, remaining at the quarterly frequency appears to be the best choice.⁸

The final (best BIC) regression estimation results are reported in Appendix Table A.2.

Rating transition matrices

An alternative approach to account for rating persistence is to use rating transition matrices. Rating transition matrices show the frequencies of how ratings at the beginning of the period (rows) change until the end of the time period (columns). Since these matrices have diagonal

⁸All results were very similar for the Akaike Information Criterion.

elements close to one and the only off-diagonals in close vicinity of the diagonal are non-zero, this also displays the tendency of ratings to remain unchanged. Mean reversion in the transition matrices shows up by rating changes toward the center of the rating spectrum carrying higher probabilities than changes away from the center.

8.1.4 Rating-implied default risk proxies

Based on the above methods two types of rating-implied default risk proxies are constructed for 5-year cumulative default probabilities.

Rating time series model and default risk regression

The first approach uses the time series regression and the following steps:

1. averaging the linearly scaled Moody's, Fitch and Standard & Poor's ratings (i.e. AAA:1, AA+:2, ..., CCC:18),
2. adjusting the average rating by the information contained in its dynamic trends via equation (8.3) (i.e by forecasting the rating based on available information up to the middle of the 5-year period: 30 months),
3. and using the logistic link in equation (8.1) to transform these adjusted ratings onto the scale of cumulative default probabilities.

Rating transition matrices

The second approach uses directly the rating transition matrices (as observed in the rating data set) and the default occurrences based on the same data set. I use this approach to obtain time-varying cumulative default probability estimates.

The following steps are carried out:

1. pooling the ratings (letter grades) of all countries and agencies and calculating 1-year rating transitions for every time point (rating transition innovations),
2. calculating the maximum ratings for each country and agency in 1-year windows and aggregating default frequencies by the initial ratings in the window (default frequencies innovations),
3. calculating a prior transition matrix and a prior default frequency vector for the time point Dec 31, 2001 by averaging 1-year (non-overlapping) transition matrices and 1-year (non-overlapping) default frequencies in the 1992-2002 time range,

4. for every time point (weekdays) after Dec 31, 2001 calculating a posterior transition matrix and posterior default frequency vector by weighted averaging the prior transition matrix (the posterior of the last time period) and prior default frequency vector with the transition matrix and default frequency innovations that uses the 1-year window ending on the given day.
5. for every time point using the posterior transition matrices and default frequencies to create cumulative default probability estimates on 1-10 year horizons.
6. spline interpolation of cumulative default frequencies (their log-odds) to a finer rating scale.

This is an EWMA (exponentially weighted moving average) filtering approach popular in finance, which combines the default and rating transition information of the latest 1-year window with information of past defaults and rating transitions. The latest 1-year window provides the most recent observations on how rating categories are linked and how much chance there is to reach default from a given rating grade within a certain time frame.

This information can be useful to monitor whether and how true default risk associated with a certain rating grade changes over time. In fact, this approach is based on the same observations of rating actions that market participants observe and which entail two separate pieces of information: (i) the issuers whose ratings have changed indicate how their individual credit risk have changed, but also (ii) these actions taken together also indicate what persistence and what rating migration risk other similarly rated sovereigns face, an indication which indirectly relates to default risk.

The resulting default probability measures use the historical information of the relationship between rating levels, rating changes and sovereign defaults just like the rating-implied default probability measures of [Remolona, Scatigna and Wu \(2007\)](#). As an improvement on this study, however, the measure derived here directly builds on expected rating mean reversion and expected rating persistence to calculate cumulative default probabilities and it allows these expectations to change over time – i.e. it does not constrain rating-implied default probabilities to be constant in time.

Time-varying default probability estimates may be important in decomposing changes of credit spreads due to underlying default risk and various types of risk premia. Ratings may be a good overall proxy to capture default risk, but their persistence and qualitative nature still leaves substantial uncertainty about the precise level of credit risk they denote. If rating actions causes market participants to update their view on rating-implied risk, then this is important to identify and separately handle from time-variation of risk premia. Moreover, because such updates to rating-implied default risk are global in nature they may contribute to increasing the proportion of the global variation seen in credit spreads to default risk rather than risk premia components.

The reason for using past information at all (not giving 100 percent weight for the latest observation) is to reduce noise and provide stability to the estimate. The fact that rating transitions

Figure 8.4: Time-varying 5-year cumulative default probability estimates

Sources: author's compilation.

Notes: The figure displays 5-year cumulative default probabilities (CDP) by rating letters and modifiers. The top panel shows CDP means for four subperiods across ratings. The mid-bottom plots show the time series evolution of CDP estimates with line corresponding to rating letter/modifiers. The left-hand plots in the figure are based on estimates with a larger smoothing parameter in the EWMA procedure than in the right-hand plots. Larger smoothing gives smaller weights to new observations.

and especially defaults are rare in the sovereign arena results in observations within each 1-year window to be very noisy approximations to plausible default risk profiles. For instance there are years when there are no observed transitions at all from a rating notch – either because there are not many sovereigns at the given rating notch to begin with (typically at the worst grades) or because ratings are so persistent (typically at the best, AAA notch) – , which would then result in a default probability of zero for the given rating grade.⁹

Figure 8.4 shows that 5-year cumulative default probability estimates did vary over time. The extent of this variation is related to the amount of smoothing applied. By far, the largest

⁹In fact choosing to only start the daily calculation of cumulative default frequencies in 2002 and to pool agency ratings (instead of using single agency observation) and to use only letter grades (e.g. AAA, AA, ... instead of more refined scales including +/- modifiers) are all necessary to start from plausible initial estimates. The late start is necessary because there were less and mainly advanced country issuers rated in the nineties and so the first in-sample default observations occurred only at the end of the decade. Choosing the coarse letter grades and pooling three agencies (assuming their rating grades are comparable) are necessary to have enough observations (and transitions) in each rating level of the transition matrix.

adjustment in the series occurred during the sovereign crisis period (see bottom panel for a zoom into this period). The adjustment appear to have two distinct phases in this period: from 2010 to mid-2011 there seems to have been increasing differentiation in credit risk across the best rating notches as associated cumulative default probabilities diverged. In a second phase in the spring-autumn developments in 2011 default risk appears to have generally increased for all high-grade issuers.

Also, somewhat counter-intuitively the default probabilities associated with high-grade issuers were significantly lower in the financial crisis period as before. This is mainly the result of the financial crisis sample identified between 2007-2009. The first half of this period was still characterized by very low (and decreasing) default probabilities associated with high-grade issuers, even lower than before 2007.

8.2 Sovereign spreads and default probabilities

8.2.1 Stylized facts of credit spreads

Appendix A.1 introduces the sovereign credit spreads data set used in the thesis. The data set spans 60 countries in the period Jan 1999 - Oct 2017 relying on 5-year CDS spreads, 5-year eurozone interest rate differentials to the Bund and JP Morgan EMBI and EEMBI credit spreads. CDS spreads are available for a larger cross-section (57 of the 60 countries), but a shorter time series (starting in 2008), whereas bond spreads data have a longer time series but smaller cross-section (37 countries).

Table A.3 provides descriptive statistics of these series (pooled data) and Figure 8.5 depicts the evolution of spreads over time.

Note that in case of bond spreads – due to incidence of negative spreads – I use a prior, 50 basis point upward adjustment of spreads before taking logarithms. A section in the Appendix discusses the effects of this adjustment and concludes that the adjustment has several advantages over the alternative of discarding non-positive spreads data. Figure A.7 graphically illustrates some of these points.¹⁰

¹⁰(1) Discarding negative spread data points biases empirical results as it creates missing values not at random, but systemically related to the lower end of the risk spectrum. (2) Adjusted log bond spreads have a lower, more stable volatility pattern as they exclude the very low 1-5 basis point data points where taking logs results in large departures from the central tendency. Looking at CDS spread data, show that log CDS spreads better align with the adjusted log bond spreads rather than the unadjusted spreads. CDS spreads were always higher than the 0-10 basis point range even though there are more high-grade issuers in the sample with CDS than bond spread and even though CDS spreads tend to be generally lower than bond spreads for the same issuer due to reasons discussed in Chapter 3. Therefore the few basis point spreads to the Bund seem to be a result of the German Bund yields being higher than the true risk-free rate and a result of liquidity related factors rather than an artifact of truly low credit risk. Thus the adjustment is more likely to correct the misalignment in credit risk rather than to create such a misalignment. (3) Adjusted log bond spreads have a volatility that is largely uncorrelated with log spread levels, (just as in the case of unadjusted log CDS spreads), whereas unadjusted log bond spreads have significant negative correlation between levels and volatility. (4) Adjusted log bond spreads have a stronger, linear relation with credit ratings in the cross-section (just as in the case of unadjusted log CDS spreads), whereas unadjusted log bond spreads have a weaker and heteroskedastic relationship with ratings.

Figure 8.5: Time series of sovereign credit spreads

Sources: author's compilation.

Notes: Time series of sovereign credit spreads. Upper plots are in nominal, basis points, term, lower plots in logs. Left-hand plots are sovereign bond spreads (bond yields to Bunds or EMBI series, adjusted by 50 basis points to avoid negative values in logs), right-hand plots are sovereign CDS spreads. Developed country spreads are colored red, emerging market spreads are blue.

Another observation in Table A.1 about both sovereign CDS and bond spreads is that their cross-sectional variation (differences across countries) are much more significant than their (common) time series variation (changes in time). This may be surprising given the larger emphasis on the time series volatility of spreads in the press and in academic papers. However, even adding idiosyncratic time series variation to the time series effects, these contain a roughly similar information compared to cross-section fixed effects alone. This property remains valid when the cross-section is restricted to just developed or emerging market countries, which further restricts cross-section variation.

Regarding subperiods of the time sample, time effects had the large variance share in the financial crisis period for both CDS and bond spreads (around 20 percent of the pooled variance). The maximum of the time series variance share is reached when the sample is restricted to the financial crisis period and it is segmented to emerging and developed countries separately. In this case – for log spreads – the time effect share rises to 47 and 67 percent for log CDS and log bond spreads on the developed country segment, respectively (variance is much lower for

nominal spreads because as argued, global effects have different loadings in the nominal case, so simple time effects are a weak approximation of commonality) and to 26 and 47 percent on the emerging market segment.

Sovereign credit spreads share several stylized facts with other financial market indicators. Their levels are persistent processes that are near unit root. In fact, unit root tests provide mixed results and mostly reject stationarity (see Appendix Table A.4), though unit root tests are known to have weak power against the alternative and the time series (even though they span nearly two decades) may still be too short to provide plausible results.¹¹

The first differences of credit spreads are stationary with distribution means near zero, left skewness (there are more extreme values of large positive changes than large negative changes) and large kurtosis (more time periods of both very small changes and very large changes than the normal distribution would imply). At higher data frequency (eg. daily, weekly) there is some weak persistence of first differences and normality is easily rejected by Jarque-Berra tests for all countries. Also at higher frequencies volatility is clustered for most time series as Engle tests are rejected (Appendix Table A.4).

Importantly for the empirical analysis in the thesis, at lower data frequencies, first differences are not anymore autocorrelated, their volatility not clustered and even normality is accepted for logarithmic spreads in half of the country sample (it is rejected for nominal spreads).

As identified by many studies in the literature sovereign credit spread time series have a substantial cross-sectional correlation. This result is robust, it is characteristic of both CDS and bond spreads, levels or first differences, at any frequency and subsamples (see Appendix Table A.5).

8.2.2 Functional form: basis points or logs?

As reviewed in Chapter 3 credit spreads are also non-trivially related to default probabilities. Besides the default risk content (default probability times loss given default) credit spreads also entail liquidity factors, structural supply-demand factors (e.g due to quantitative easing measures), factors possibly related to market sentiment and herding. In much of the literature and in the thesis all of these non-default risk components are commonly referred to as risk premia.

The global co-movement of spreads can be due to various factors. It could be that global fundamentals or their expectations have a systemic effect on spreads, where global fundamentals can be related to growth prospects, prospects of a global banking crisis or even global trends in political uncertainty and instability. Global co-movement can also be explained by global liquidity conditions and fluctuation in global investor sentiment. Importantly, these factors may

¹¹Credit spreads are constrained to be positive and CDS spreads have a theoretical maximum of 10000 basis points, so that theoretically these series cannot have unit roots. Estimation between CDS and bond spreads and fundamentals should also be theoretically linked by arbitrage arguments even if reversion to fundamentals-implied means is slow. Therefore estimating the levels relationship between spreads and fundamentals should not result in spurious results even if it is ridden with problems stemming from strong autocorrelation and collinearity of fundamentals.

affect both the true default risk component in spreads (i.e the interest rate differential that is provided for holders of risky bond investors for assuming the risk of default) and the risk premium (the additional component that is provided for risky bonds being a bad hedge against systemic risk). By contrast, idiosyncratic country fundamentals that are not correlated with the systemic risk yield a default risk component but no risk premium, at least if bond portfolios are able to diversify these risks. However, [Amato and Remolona \(2003\)](#) argue that in case of bonds this diversification would necessitate so large number of bonds, which is unrealistic in the real world (especially sovereigns) and hence idiosyncratic risk also receives a premium.

Levels vs volatility and correlations

Theoretically, sovereign spreads include a risk premium for the covariation with general market returns, i.e portfolios of other risky assets (or even more generally for the covariation with consumption utility as in CCAPM). When other risky assets fall, sovereign spreads tend to rise, making them a bad hedge against the market portfolio. (This relationship is confirmed by Appendix Table A.5.) Standard arguments in finance therefore warrant a positive risk premium within sovereign credit spreads, the magnitude of which should be related to the covariance of these assets with the market portfolio. For countries whose spread varies much more with the market return (due to either their higher volatility or higher correlation with the market), the risk compensation should also be larger. This would make levels of spreads dependent on covariance.

Figure 8.6: Spreads versus correlation with other spreads

Sources: author's compilation.

Notes: Levels of spreads (log spreads bottom panel) versus the correlation of spread (log spread) changes with cross-section means (of other country spread changes). Log bond spreads adjusted by 50 basis points.

Increasing covariation with the market at higher sovereign spreads may be due to larger correlations at higher spreads, due to higher volatility of spreads at higher spread levels or both.

Figures 8.6 and 8.7 investigate this question. Based on Figure 8.6, there is no clear pattern emerging between correlations and spread levels for either bond or CDS spreads, nominal or logarithmic specifications, in either subperiods. Thus, higher correlation with the common factor does not seem to either increase or decrease spreads in general and it cannot account for the risk premia increasing with spread levels.

In contrast, there is a strikingly strong and robust log-log relationship between the volatility of nominal spreads and nominal spread levels (upper panel of Figure 8.7). This relationship holds for both bond spreads and CDS spreads and all subperiods studied on the sample.

Figure 8.7: Spreads versus volatilities

Sources: author's compilation.

Notes: Levels of spreads (log spreads in bottom panel) versus volatility. Volatility is calculated as the standard deviation of first differences of spreads (log spreads). Log bond spreads adjusted by 50 basis points.

The relationship is linear in the log-log plane. What this means is that nominal spreads have much larger spread fluctuations measured in basis points for more risky sovereigns with higher mean spreads. Modelling sovereign spreads simply in their nominal form (e.g. the interest rate differentials as common in the eurozone sovereign risk literature) necessitates a more complicated innovation structure (lognormally distributed innovations with scale parameter linked to the level of the spread) to account for the heteroscedasticity. Accounting for such heteroscedasticity also necessitates betas (sensitivities to common variation in market spreads) that depend on the relative riskiness of the sovereign to the market, because without accounting for this, residuals will strongly depend on the level of the common factor and thus will not be idiosyncratic.

Also, and more to the point of the thesis, the errors of regressions of nominal spread levels

on fundamentals will also be dependent on the level of spreads. This will cause larger spread countries to be much more influential in any parameter estimation in linear models. Any country-specific noise or omission affecting these large spreads will bias parameter estimates due to finite samples. Sample selection is thus likely to have a large effect on parameter estimates. Estimates of the effects of fundamentals on spreads will be sensitive to changes in the sample both in the cross-section (i.e. whether or not Argentina or Greece are included) and the time sample (i.e. whether or not the crisis sample is included), because fundamental proxies are not likely to soak up all spread volatility variation by levels. Therefore regression models of nominal spreads on fundamental proxies are likely to inherit heteroscedastic errors and they are likely to result in non-robust estimates of effects of fundamental determinants.

In contrast, the volatility of log spreads (the standard deviation of log spread changes) displays no such relationship with log spread levels. Although there are clear differences in sub-period volatilities of log spreads (see the CDS lower right-hand panel, where volatility of log spreads gradually decreases throughout the sample), this does not translate into generally lower or higher log spreads. Also the cross-sectional variation within periods does not suggest either a positive or a negative relationship between volatility and spreads. Thus log spread levels appear to be distributed independently of log spread volatility, which makes their modelling much simpler.

To sum up, the above figures suggest that (i) cross-country correlations are positive and significant, time-varying, but are independent of spread levels, (ii) volatility in the changes of spreads is dependent on spread levels, (iii) volatility of changes in log spread levels is independent of log spread levels. It appears then, that the crucial drivers of sovereign credit spreads have a multiplicative rather than an additive effect. Of course it may be that some determinants of credit spreads are additive in nature, these figures only tell us that the effect of these determinants are swamped by others with multiplicative effects. Either way, modelling spreads in logarithms seems to better fit the data.

8.2.3 Link between spreads, ratings, default probabilities and fundamentals

As seen previously in this chapter and in Chapter 3, credit ratings increase in default probabilities as agencies claim. This relationship is best characterized as a logistic link, however, rating persistence and rating lags obscure this relationship with regard to shorter time series in levels and especially with regard to changes of these series. If the default probability of a country increases, ratings are expected to adjust only gradually and only to the extent that this increase is expected to be of a permanent nature (i.e. due to the through-the-cycle methodology).

Initial calculations

Sovereign spreads are also partly determined by default probability, but this relationship is also obscured by risk premia (the risk-neutral, objective default probability is priced not the true subjective probabilities) and by the expected haircut, which may or may not depend on default probabilities. As derived in Chapter 3, bond spreads and CDS spreads are linked somewhat differently to default probabilities and haircut (loss given default):

$$S_{i,t}^{CDS} = E_t^Q[\lambda_{i,t+1}h], \quad S_{i,t}^{BOND} = E_t^Q \left[\frac{\lambda_{i,t+1}h}{1 - \lambda_{i,t+1}h} \right] (1 + r_t^f).$$

To simplify, it is common to assume a fixed haircut that is independent of default probability (e.g. conventionally 0.4 haircut for emerging markets and 0.25 for developed markets are used).¹² Note that the risk-free rate r_t^f is also known at pricing and is therefore outside of expectations.

Taking logs and separating the default intensity components in a later convenient form, we have

$$\begin{aligned} \log S_{i,t}^{CDS} &= A^{CDS} + \log \frac{\lambda_{i,t+1}^Q}{1 - \lambda_{i,t+1}^Q}, \\ \log S_{i,t}^{BOND} &= A^{BOND} + \log \frac{\lambda_{i,t+1}^Q}{1 - \lambda_{i,t+1}^Q}. \end{aligned} \quad (8.4)$$

with

$$\begin{aligned} A_{(i,t+1)}^{CDS} &= \log h_i + \log(1 - \lambda_{i,t+1}^Q), \\ A_{(i,t+1)}^{BOND} &= \log(1 + r_t^f) + \log h_i + \log \frac{1 - \lambda_{i,t+1}^Q}{1 - \lambda_{i,t+1}^Q h_i}. \end{aligned}$$

Regarding the separated terms in A , both have a $\log h$ component. In case of the conventional recovery rate assumption, it subtracts 0.9 (emerging markets) and 1.4 (advanced markets) from log spreads. Based on the descriptive statistics, log spreads have a range of 4-5 units, so the haircut is a significant factor especially if h is smaller than assumed here. This factor is fixed and assumed independent of default intensity and market returns so it does not affect dynamics, but since it is customarily calculated to be higher for emerging markets it should be noted as a factor that relatively reduces spreads of advanced countries relative to emerging markets.

The term in bond spreads $\log(1 + r_t^f) \approx r_t^f$ has an order of magnitude smaller effect (e.g. a 100 basis points increase in risk-free rates would imply a 0.01 increment). This automatic effect of the risk-free rate thus appears too small to be material. If the risk-free market rate has an effect on sovereign spreads it is more likely to be rooted in the correlation of market rates and

¹²Whether this assumption is appropriate may be debated. Supporting these is market convention and that pricing models that investors commonly use have these values set as default input. However, for instance, [Sunder-Plassmann \(2018\)](#) brings contrary evidence.

default probability.

The default intensity adjustment term $\log(1 - \lambda_{i,t+1}^Q)$ in A^{CDS} is due to the denominator $(1 - \lambda_{t+1}^Q)$ missing from S^{CDS} because accrued premia are conventionally paid (netted out) at default. However an alternative assumption of default occurring early in the period would allow this denominator to appear at least partly in the CDS spread price. This factor only becomes significant at very high default probabilities, when it introduces a downward adjustment in the log spread vs default probability relationship increasing in default probability (for 'CC' rated issuers it would subtract 0.7 of log spreads, but around 0.05 for the average BB rated emerging market spreads). This is the term that makes A time and country-specific. However, taken that this factor is only relevant in extreme cases, we can disregard it and assume A to be a constant adjustment largely dependent on the size of the haircut.

The default intensity adjustment term $\log(1 - \lambda_{t+1}^Q)/(1 - \lambda_{t+1}^Q h)$ in A^{BOND} acts similarly to reduce log spreads at high default intensity with the adjustment the same order of magnitude as in case of CDS spreads.

To link ratings to sovereign credit spreads we need to assume a functional form for the difference between the risk-neutral measure Q and true real-world measure P .

I choose the form $\lambda_{t+1}^Q/(1 - \lambda_{t+1}^Q) = \eta_t[\lambda_{t+1}^P/(1 - \lambda_{t+1}^P)]^{\zeta_t}$, which allows spreads to include the true default probability implied compensation, and other priced factors, which increase either independently of (η) or proportionately with the log-odds of default risk (ζ) . Denote by A the respective adjustment terms of bond spreads and CDS spreads. Log spreads are then given by

$$\log S_{i,t} = A_i + \log(1 + \eta_t) + (1 + \zeta_t) \log \frac{\lambda_{i,t+1}^P}{1 - \lambda_{i,t+1}^P}.$$

Finally, we can use equations (8.1)-(8.3) to recover the relationship of spreads and credit ratings and SDV:

$$\log S_{i,t} = A + \log(1 + \eta_t) + (1 + \zeta_t)(a + bRAT_{i,t} + u_t) \quad (8.5)$$

$$\log S_t = A + \log(1 + \eta_t) + (1 + \zeta_t)E[SDV_{i,t}]/s. \quad (8.6)$$

These equations state that log spreads are linearly related to current ratings and the current expectation of SDV.

The sensitivity of spreads to ratings is dependent on the sensitivity of the log odds of default to ratings (b) and an element of risk pricing (ζ_t). The reduced form estimates of spread sensitivity to ratings can thus suggest whether the default risk proportional part of the risk premium ζ_t is an important factor in pricing and whether it is time-varying.

Empirical estimates: spreads vs ratings

Turning to the data, Figure 8.8 confirms that linearized ratings are related to logarithmic credit spreads as implied by equation (8.5). Again the nominal specification (upper panel) not only has the problem that expected spreads increase exponentially in terms of ratings (this could be handled by explicitly modelling exponential ratings in spread regressions), but that the dispersion around these conditional expectations also increases exponentially. Logarithmic spreads appear to avoid these problems.

Figure 8.8: Spreads versus ratings (pooled data)

Sources: author's compilation.

Notes: Sovereign bond and CDS spreads in nominal and logarithmic terms vs sovereign linearized credit ratings (agency averages). Log bond spreads adjusted by 50 basis points.

To further investigate the roots of this link we can look at the time series vs cross-sectional components of this relationship.

Time effects (time series of cross-section means) of both ratings and spreads are displayed in Figure 8.9. There is only a very weak association between these series. As seen before, spreads and ratings both decreased in pre-crisis periods (available only in the bond spreads sample), then spreads increased without any material change in the means of ratings.

This could have been either a result of ratings becoming a worse proxy of true default risk as agencies lagged the market by worsening ratings on (developed country) issuers or it could also have been the result of increased pricing of (sensitivity to) credit ratings.

The sovereign crisis period however entailed somewhat lower mean credit spreads than the height of the financial crisis with ratings gradually rising (deteriorating).

Finally, in the 2013-2016 period, mean ratings and mean spreads have been largely stable.

Appendix Table A.6 shows that time series correlations are varied across periods and assets. Correlations are generally low positive between levels series and close to zero for changes.

Figure 8.9: Spreads and ratings time-series comovement

Sources: author's compilation.

Notes: Sovereign bond and CDS spreads in nominal and logarithmic terms vs sovereign linearized credit ratings (agency averages). For each time period cross-section means of spreads and ratings are calculated and these time series are plotted against each other. In case of log bond spreads 50 basis point adjustment is applied.

Figure 8.10: Spreads versus ratings in the cross-section

Sources: author's compilation.

Notes: Sovereign bond and CDS spreads in nominal and logarithmic terms vs sovereign linearized credit ratings (agency averages). For each country cross-section the time series means of spreads and ratings are calculated and these cross-sectional series are plotted against each other. In case of log bond spreads 50 basis point adjustment is applied.

By contrast, the cross section relationship is stable and strong. This is true for all of the four subperiods and for both types of credit spreads. Figure 8.10 demonstrates this by plotting the cross-section effects of spreads (nominal, log, CDS and bond spreads) against cross-section effects of ratings.

Table A.7 in the Appendix provides correlation statistics.

Empirical estimates: spreads vs default probabilities

The failure of the time series component of ratings to pick up time series fluctuations in spreads may be the consequence of ratings being a bad proxy of true credit risk. If there were many observations of default occurrences attributed to initial rating levels then this could be directly checked, moreover (log) spread pricing could then be directly evaluated using such default frequencies.

Figure 8.11: Log CDS spread correlation with ratings and rating-implied CDP

Sources: author's compilation.

Notes: Correlation coefficient between the levels of ratings and log CDS spreads in the cross-section (upper panel) and over time (bottom panel).

Unfortunately – as told before – one key characteristic of sovereign risk analysis compared with the analysis of corporate credit risk is that it cannot rely on high-frequency, direct observations of time-varying default rates, because the number of observations of defaults is very low. We can still aim to get closer to such an estimate by relying on the few available default observations complemented by information from rating transitions.

I showed earlier a way to calculate time-varying cumulative default probabilities linked to rating grades based on innovations in the rating transition matrix and default frequency vectors. Such a measure may be useful in picking up general expectations of rating changes from rating actions in just a few precursor countries. Whether these actions really prove to be characteristic of more general tendencies, however, or are rather characteristic only of the given country whose rating has changed is not evident and is an empirical issue to investigate. If the time-varying default probabilities were a better measure of true default probability than ratings, then it could be expected to have higher correlation with logarithmic sovereign spreads. Nevertheless it has to be emphasized that such time-variation is still based on rating actions and cannot help the

Figure 8.12: CDS spreads vs rating-implied Cumulative Default Probabilities

Sources: author's compilation.

Notes: The left panel displays the evolution of the mean of log CDS spreads and mean log 5-year cumulative rating-implied default probabilities (CDP, calculated from rating transitions and observed default rates with small smoothing and large smoothing) for separately for emerging market and developed country issuers. The right panel shows a scatter plot of pooled CDS spreads and CDP observations on log-log scales.

problem of a general lag of rating agencies to follow changes in default probabilities in a timely manner.

Figure 8.11 clearly does not support the idea that time-varying cumulative default probabilities are a better gauge of default risk than ratings themselves. It seems that ratings have a higher correlation with spreads in both the cross section and in the time series than the calculated time-varying default probabilities. These time-varying measures only appear to be better in the time series characterization of spreads in the sovereign crisis subperiod.

Figure 8.12 left panel shows that there was a marked upward shift in default probabilities associated with the developed country segment of in the sovereign crisis period, although the extent is largely dependent on the estimation method (how much EWMA smoothing is applied). The time series of log CDS spreads versus log default probabilities also indicates some time variation in the risk premium (the difference between these series). Note that the correction for haircut is not applied in the figure so that the premium is larger by about 1 unit than the simple difference between respective log CDS and log CDP series.

The right panel of the figure plots the pooled log CDS series against log cumulative default probabilities. The green line displays the fair price of credit risk in case of full debt writeoff and the difference between scatter points and the green line can be understood as risk premia factors, liquidity factors or transaction costs. Again haircuts are not accounted for in the figure, but if they were included, this would shift the scatter points to the right. In fact such a correction would closely align the CDP and CDS for the highest risk observations (and then make the risk premia for lower risk observations even larger).

Both the time series and pooled figures show that the premia (in log terms) decreases as the

default risk increases, for instance premia appears to be significantly larger for developed countries than emerging markets. Therefore a marginal percentage worsening in the true cumulative default probability commands a smaller compensation for the extra risk.

This result may originate from various causes. Perhaps transaction costs are decreasing in percentage terms (but increasing in basis point terms), which may command larger percentage term premia at higher spreads. It could also be a consequence of the risks of credit changes being tilted toward worsening for high grade issuers (compared to the mean that is taken into account by CDP) and toward improvement (compared to the expected – high – default risk) for risky sovereigns. Or it may be that market risk connected to changes in the risk free rate could have a larger relative effect for smaller spreads.

Solving this puzzle is an interesting question for future research.

Link to fundamentals

Based on equation (8.6), any factors and so macroeconomic variables that linearly affect SDV also linearly affect ratings and the logarithmic credit spreads.

However, it needs to be emphasized that while the linear relationship between ratings and logarithmic spreads are clearly supported by empirical evidence (at least in the cross-section), less can be said about linearity of macrovariables with ratings and logarithmic spreads. Conclusions of Chapter 2 clearly favored non-linearity and more complex relationships, and in Chapter 3 also, ratings were noted to be set by agencies based on non-linear formulas in case of many variables.

There are still some arguments in favor of (generalized) linear models. Empirical papers assessed in Chapter 4 formed reduced form models of spreads or log spreads to be linearly related to macrovariables. The popular Cox proportional hazard model among (corporate risk) practitioners $\lambda_t = \phi_t \exp(X\beta)$ also – indirectly and approximately – relates log spreads to linear effects of fundamentals. In the theoretical and quantitative models of this thesis many fundamentals were found to have close to linear effects on SDV and (based on further additional assumptions on SDV dynamics) this was shown in the current chapter to carry forward to logarithmic spreads as well. It seems then, that even though theory in principle would warn against this, many practical models do linearly relate fundamentals to logarithmic spreads. Actors who set prices in bond and CDS markets may also rely on such models, and this may act to reinforce such simple relationship between spreads and fundamentals.

8.2.4 Implications for modeling

First, spreads are better modeled in a logarithmic functional form than in simple nominal (basis point) terms, because:

- logarithmic spread changes at low frequencies are close to being normally distributed, whereas nominal spread changes are not normal due to higher kurtosis;

- spreads are exponentially related to (linearized) ratings and the log-odds of default;
- the volatility of nominal spreads is strongly linked to spread levels, whereas the volatility of log spreads is independent of spread levels, which implies that the most important drivers of spreads are related multiplicatively to spreads;
- large heteroscedasticity of nominal spreads could introduce sampling bias in parameter estimates, whereas parameter estimates in log spread models are more likely to be robust to sample selection.

Second, when modeling the fundamental determination of spreads with country fundamentals proxied by ratings, it is the cross-sectional dimension rather than the time series dimension, which contains useful information. The time series variation on the other hand has a large commonality component in the country cross-section.

- Perhaps the reason is that the relationship of sovereign credit spreads and fundamentals are not robust, which makes strategies built on mean reversion to fundamentals costly and risky to implement. Then only large credit spread deviations from perceived fundamentals are exploited and reversion to fundamentals remains slow and better grasped at lower frequencies.
- This may also be due to problems of ratings as a proxy of fundamentals: ratings are lagged and the through-the-cycle methodology of agencies neglects temporary fundamental (business cycle-related) effects on spreads.
- However information about many fundamentals important for creditworthiness (e.g. political stability and institutions, funding liquidity) are also costly to gather as proxies are noisy and infrequently available.
- Sovereign spreads (especially in logs) also contain more cross-sectional than time series variation and time series variation is usually linked to global rather than local variables.

The dynamics of spreads could therefore be modelled as having a component with reversion to fundamentals in an error-correction form and additionally a component that is dependent on common (global and regional) shocks.

CHAPTER 9

Methodology

This chapter turns to the methodological tools that aim to assess whether there is time-variation in the effects of a set of explanatory variables on the dependent.

The first section briefly discusses some statistical inference methods proposed by the statistical literature that are relevant in this regard. Most of this literature focuses on the more difficult case of a single cross-section with potential breaks in the time series of observations (or in a panel context where effects are cross-sectionally heterogeneous). The context of the thesis (and a larger part of the sovereign risk empirical literature) connects to a simpler case, because I assume homogeneity of effects across cross-sections (country units) and thus the availability of the panel constitutes repeated measurements of the same (random) effect allowing obtaining estimates of their distribution by the cross section. Nonetheless these tools or their extensions for the case at hand make it useful to understand their properties.

The validity of tests used in both the statistical and the empirical sovereign literature rely on various assumptions being true. The second section of this chapter points out that based on the preliminary empirical analysis of the Chapter 8 several of the assumptions are clearly violated. The section also demonstrates how the results are likely to be influenced both in theory and practically, in the current situation at hand by conducting Monte Carlo experiments. The last part assesses main conclusions of the analysis and proposes methods to be used in the next chapter that delivers the main empirical results of the thesis.

9.1 Tools for assessing time-variation of effects

The seminal reference in the econometrics literature that assesses time-variation in effects in regression models is [Chow \(1960\)](#). The structural break tests derived in this paper assess whether the difference of regression coefficients estimated in a regression framework for an initial data sample (subperiod 1) and a new subsample (subperiod 2) implies that the underlying (population) effects are different. The Chow test is based on the methodology of the analysis of variance (ANOVA), which tests the null hypothesis that observations in two (or more) samples originate from identical distributions. The alternative hypothesis is that observations are from identical distributions with the exception of a shift in the mean effect. The logic of the test is that if there is a structural break in the effect, then the regression residual sum of squares (RSS) computed with the same least-squares coefficients (restricted model) for the samples will be significantly larger than the residual sum of squares computed with different coefficients for the samples (unrestricted model). As in the ANOVA, the Chow test uses the F -distribution to discern whether the RSS improvement introduced due to added coefficients is statistically significant.

Based on the idea of considering structural breaks vs no breaks as parameter restrictions, Wald-tests, LM (Lagrange Multiplier)-tests and LR (Likelihood Ratio)-tests are available to use in large samples that each have a limiting distribution of $\chi^2(q)$, where q is the difference of estimated parameters between the unrestricted and restricted models.

Based on the results of this chapter I use the F-tests to test in the next chapter so I will define it here.

Consider the regression model

$$y_t = X_t \left(\sum_{is}^{Ns} D_{is} \beta_{is} \right) + Z_t \gamma + \epsilon_t,$$

where y_t is a $T \times 1$ vector of dependent observations, X_t is a $T \times K$ matrix of regressors, whose effects are considered to potentially change in time, with the effect β_{is} relevant in the subsample identified by the dummy variable D_{is} . $Z_t \gamma$ identify the effect of other variables included in the regression and ϵ_t are the $T \times 1$ residuals assumed to be iid normal.

The F-test compares the sum of squared residuals of the restricted (RSS_r) and unrestricted (RSS_u) models and assesses whether the increase in residual squares in the restricted model can be attributed solely to the degrees of freedom (there are fewer regressors for the same number of observations). If the disturbance is independently and normally distributed, then the test statistic

$$F = \frac{(RSS_r - RSS_u)/(K_u - K_r)}{RSS_u/(N - K_u)}$$

has an F-distribution with parameters $(K_u - K_r, N - K_u)$ with N the number of observations, K the number of parameters.

There are several underlying assumptions of the F-test in the Chow and the Wald-, LM-, LR-type tests. They assume the independence of disturbances (i.e the dependent variable after regressor effects are controlled for), that disturbances originate from the same mean-zero, uniform variance distribution. The F-test assumes normality and is valid in finite samples, whereas the other tests do not have a distributional restriction but are valid only in large samples (the Central Limit Theorem guarantees asymptotic normality).

Both the independence assumption and homoscedasticity assumptions are important. Clearly, if the variance of the disturbance is subject to change between the two samples, then the estimated residual sum of squares is subject to change due to both the effect of an unaccounted-for-structural break and heteroscedasticity. The independence of observations is also important, because these tests rely on the property that the variance of the sum of independent variables is simply the sum of their variances. When observations are correlated then this sum may be either larger (positive correlations) or smaller (negative correlations).

Lim, Li and Lee (2010) provides instructive Monte Carlo simulation evidence regarding how the LR-test behaves when the sample is correlated. Based on their analysis, when there is correlation between observations the LR-test nevertheless achieves the nominal size (rejects 0.05

of the simulated cases at this significance level) in large samples and it significantly over-rejects in finite samples, but at roughly the same rate in both the correlated and uncorrelated cases. However, when correlation changes across the subsamples, the LR-ratio test over-rejects.

The Chow test is concerned with the case of a single possible breakpoint at a known time point. Developing methods that can identify multiple breakpoints with unknown timing have been the subject of a substantial literature in the past decades (see Perron et al., 2006, for a review). Important contributions are Andrews (1993) and Andrews and Ploberger (1994) that derive the popular estimators (supremum, average and exponential Wald, LM, LR-tests) that test the existence and identify the location of an unknown breakpoint in the effect. Bai and Perron (1998) develop a sequential procedure to find multiple unknown breakpoints. Hansen (2000) considers the case when there is a structural break in the data generating process of the regressors, and proposes a bootstrap-based inference method to deal with the resulting complications.

A line of research has dealt with the intricate relationship of unit roots and structural breaks (Perron et al., 2006; Perron, 2017, provide reviews). When variables are unit roots, cointegration testing can decide whether there is a significant reversion to a long-term relationship between the variables. However if there is such a relationship but it is subject to structural breaks, then standard cointegration tests will reject cointegration. The Gregory and Hansen (1996) tests can help in this regard. Unfortunately, when the true data generating process is close to unit root these tests have low power whether there are breaks in the data or not.

With panel data, the additional information of repeated measurements due to the cross-section dimension adds power to tests to the degree of independence of panel units and whether the coefficients can be assumed to be homogenous across the sample (i.e how much added information is contained relative to a single time series). For panel data, Bai and Carrion-I-Silvestre (2009) provides unit root tests for cases with structural breaks, and methods in Westerlund (2007) and Banerjee and Carrion-i Silvestre (2015) can be used for cointegration testing in these cases. Further useful references are Baltagi, Feng and Kao (2016) a paper that estimates structural breaks in heterogenous panels with common correlated effects and Hansen (1999) that estimates smooth changes in effects linked to a threshold variable in fixed effects panels.

Nonetheless there are several difficulties for practical applications as most of the methods are valid asymptotically and are based on various restrictive assumptions. Regarding the current application in the thesis, restrictive assumptions often include no missing data, regressors observed without error, the independence of the disturbances and regressors (no endogeneity) and correct specification of the model. It appears to be the best approach to evaluate estimation methods and tests in Monte Carlo simulations that are designed particularly for the application and data features at hand, which is one of the goals of this chapter.

9.1.1 The methods in the sovereign credit risk literature

Chapter 4 discussed empirical papers that estimate the effects of fundamentals on sovereign credit risk variables. The last section of Chapter 4 focused on studies that assessed time variation in effects. In Table 4.4 I grouped papers by the methodology used to identify structural breaks in the effects. Here I summarize the most popular methodologies in a bit more detail.

The most popular framework for analyzing the change of effects was the simple use of split sample estimates in the fixed effects panel framework. In most papers listed in Table 4.4 this amounted to estimating panel regression for the pre-crisis/crisis/post-crisis cases and then comparing effects (and their significance) by inspecting estimated coefficients and t-statistics. In most cases the real question was whether or not an effect became significant/lost significance during the crisis rather than whether the effect (of a particular sign) changed in magnitude. Such simple analysis was sufficient for this purpose.

Another popular and related method used crisis dummies. Most papers studying wake-up call effects belong to this group. In these specifications the general (no-crisis) effects were separated from the crisis regime effects by adding and interacting dummy variables for the timing of the crisis with the regressors of interest. Then, the significance based on the t-statistics could be gauged to identify a break in the effect. This specification is better able to highlight the changes in effects compared to the split samples regressions because it tests whether the added effects compared to the baseline (no-crisis) effect are insignificant rather than testing whether the effects are significantly different from zero. A substantial difference between the two specifications is that split samples do not assume homogeneity of the error variance structure (and the variance-covariance structure of regressors) across regimes, but crisis dummies specifications usually do. If these assumptions are valid, then the additional data more efficiently estimates the homogenous parameters in the model (regressor effects and error variance) compared to splitting the samples.

Time-varying parameter models instead assume that the effects of regressors are latent (state) variables and identify the expected value and variance of these variables by filtering methods. The underlying state space models introduce a dynamic process (usually a random walk or AR(1)) for the state variables. Time-varying parameter models have the advantage compared to the previous methods that possible breakpoints are not a priori imposed, but they are identified endogenously. Also, the estimated parameter confidence bounds make it easy to identify the points in time when effects became significantly different from zero. The possible drawbacks include computational issues (e.g numerical stability, runtime of estimation) and questionable validity of inference, when disturbances do not adhere to distributional assumptions imposed by the model.

A few papers used regime-switching models, where the effects have a few estimated values and the effects are assumed to jump between these values by estimated probabilities. Again, this approach is useful for identifying breaks in effects endogenously from the data rather than a

priori imposing these. The key (potential) benefit compared to arises in situations when there are more abrupt changes in the effect. If the effect changes smoothly over time, then time-varying parameter models are more appropriate.

Other studies estimated parameters in rolling regressions or used kernel-based methods for identifying local (linear) effects. These can similarly identify shifts in the estimated effects endogenously and dynamics are not restricted by the parametric model of TVP and regime-switching models. Nevertheless the choice of the estimation window/kernel bandwidth needs an ad hoc decision to which the results may be sensitive.

9.2 Methodology used in the thesis

The empirical sovereign risk literature has largely reached a consensus that fundamental effects on sovereign credit risk variables are time-varying, however there is no agreement as to which fundamentals have significantly changed. As conjectured in Chapter 4, the methodology and model specification, the sample used and regressors included could all contribute to the heterogeneity in results.

In the next chapter I test the hypotheses outlined in Chapter 7 and at the same time attempt to explore how variation in model setting, estimation techniques could lead to heterogeneity of results. When there is a difference between results derived from two different models, the question to decide is which model assumptions better correspond to other observations (stylized facts) of the sample. When it is the sample at fault, the difference is likely to be caused by omitting an important factor influencing sovereign risk.

To be able to relate to the literature I use a general model specification, whose special cases encompasses many of the existing empirical studies. Formally the general specification I investigate is:

$$(\log)S_{i,t} = \beta_t' Z_{i,t} + \gamma_i' W_t + U_{i,t}, \quad (9.1)$$

where $S_{i,t}$ is the sovereign risk indicator (e.g. rating, spread) of country $i = 1, 2, \dots, N$ in period $t = 1, 2, \dots, T$, $Z_{i,t}$ is a $(K \times 1)$ vector of fundamental proxies characteristic of the country and the time period. The parameter vector of interest is $\beta_{t(1 \times K)}$, which is primarily allowed to vary in time and is assumed homogeneous across countries. Other time varying common effects with potentially heterogeneous effects are captured by $\gamma_i' W_t$, while $U_{i,t}$ is the component unexplained by these variables that may include various explicit variables unrelated to fundamentals, fixed effects, global factors and random disturbance.

I will consider several processes for the coefficient vector β_t :

1. As the most restrictive case β is fixed throughout the sample.

$$\beta_t = \beta_0. \quad (9.2a)$$

2. The case of the effect varying by subsamples (relating to the split samples and crisis dum-

mies cases in the literature), where

$$\beta_t = \sum_s \beta_t^s D_t^s \quad (9.2b)$$

with D_t^s the indicator variable that takes the value of 1 in the subsample s and 0 otherwise.

3. To grasp the crisis dependence of effects in an alternative way I will consider the case, where the effect is linked directly to the effect of a common proxy of financial market stress, the VIX index, in which case

$$\beta_t = \beta VIX_t. \quad (9.2c)$$

4. As the most flexible form, the effects are estimated separately for each cross-section and trivially

$$\beta_t = \beta_t. \quad (9.2d)$$

5. To grasp the effect in a time-varying parameters form, I estimate a state space model in which (9.1) is the measurement equation and the state dynamics are given by

$$\beta_t = \beta_{t-1} + w_t, \quad w_t \sim iid(0, Q), \quad (9.2e)$$

thus β is assumed to follow a random walk with the vector w_t denoting multivariate normal innovations.

These specifications with appropriate definition of $U_{i,t}$ and W_t encompass several cases seen in the literature:

- The standard levels specification (either log spreads, spreads or ratings as dependents) in the literature has $S_{it} = \beta Z_{it} + \gamma_i W_t + U_{it}$ with the unexplained term U_{it} assumed to contain fixed effects and a disturbance component $U_{it} = \alpha_i + u_{it}$. Other studies that alternatively allow time fixed effects have α_t also in U_{it} , then $\gamma_i W_t$ has to be dropped.
- The first-difference specification in the literature is $dS_{it} = \beta dZ_{it} + \gamma_i W_t + \epsilon_{it}$ (in which case the unexplained component has a disturbance and cross-section fixed effects become unimportant). This can be reproduced in the above formulation by $U_{i,t} = U_{i,t-1} + \epsilon_{i,t}$ (the unexplained component is a random walk).¹
- Crisis and wake up call effects are usually tested within these frameworks, but with the effect also dependent on crisis dummies as in (9.2b).
- Error-correction specifications integrate the levels and the first-differences specifications by including the disturbance of the long-term equation in the short-term equation. With $U_{it} = (1 - \kappa)U_{it-1} + \epsilon_t$ the specification becomes $dS_{it} = -\kappa(S_{it-1} - \beta X_{t-1} - \gamma_i W_{t-1}) +$

¹We can write $S_{it} = \beta Z_{it} + \gamma_i W_t + U_{i,t-1} + \epsilon_{i,t}$ and $S_{i,t-1} = \beta Z_{i,t-1} + \gamma_i W_{t-1} + U_{i,t-1}$. Taking the difference leads to $S_{it} - S_{i,t-1} = \beta(Z_{it} - Z_{i,t-1}) + \gamma_i(W_t - W_{t-1}) + U_{i,t-1} + \epsilon_{i,t} - U_{i,t-1}$, which is $dS_{it} = \beta dZ_{it} + d(\gamma_i W_t) + \epsilon_{i,t}$.

$d(\beta X_{it}) + d(\gamma_i W_t) + \epsilon_{it}$.² In much of the literature that assumes cointegration between credit spreads and its determinants allow more flexible form of the short-run dynamics, allowing innovations (other exogenous stationary variables also enter as separate terms in the short-run equation). The pooled mean group estimation applied by several studies in the literature allows cross-section heterogeneity in the short run effects. Others assume homogeneity in both long-run and short-run effects (mean group estimates) and again others assume both long- and short-run effects to be heterogenous.

- Time-varying parameter models where β is assumed random walk. With the random walk assumption and $U_{i,t} = U_{i,t-1} + \epsilon_{i,t}$ one gets the intuitive Oaxaca-Blinder decomposition of the relative importance of parameter effects vs fundamental changes: $dS_{it} = \beta_{t-1}\Delta Z_t + \Delta\beta_t Z_{t-1} + U_{i,t}$.³

9.2.1 Preferred specifications

The above specifications are general enough to relate to a significant part of the literature including papers focused on time-varying effects.

However, only a part of these specifications align with observed stylized facts discussed in Chapter 8. Notably, I argued that a logarithmic spread specification should be used to avoid having to model a volatility structure that is correlated with the dependent. Logarithmic spreads models are well-behaving in the sense of not exhibiting stochastic volatility effects and their first differences are also close to being normally distributed.

Unit root tests were mixed for both credit spreads data and credit ratings. Theoretically both have natural bounds that make these series stationary, but the strong (near unit root) persistence in levels calls for estimation methods, which can account for the strong autocorrelation.

Another obvious feature to account for is cross-country correlations in credit spreads. As discussed by the literature and also apparent from the data set used, credit spreads co-move globally (see references in Chapter 4) and there is further correlation between regional peers (Kocsis, 2014). The global factor identified by the first principal component of spread changes strongly co-moves with globally important financial stress indicators such as the VIX index and the US high yield spread.⁴

The two preferred specifications I rely on in the next chapter are a simple levels specification (9.3a) and a dynamic specification (9.3b). In the levels specification,

²To facilitate notation I drop $\gamma_i W_t$ here, it's role is similar to βX_t . We can substitute the lag of the disturbance term into the levels equation, $S_{it} = \beta X_{it} + (1 - \kappa)U_{it-1} + \epsilon_t$. Then $S_{it} - U_{it-1} = \beta X_{it} - \kappa U_{it-1} + \epsilon_t$. Since $U_{it-1} = S_{it-1} - \beta X_{t-1}$, substituting into the previous equation, we get $S_{it} - S_{it-1} + \beta X_{it-1} = \beta X_{it} - \kappa(S_{it-1} - \beta X_{t-1}) + \epsilon_t$, which is $dS_{it} = -\kappa(S_{it-1} - \beta X_{t-1}) + d(\beta X_{it}) + \epsilon_t$.

³Then $S_{i,t} = (\beta_{t-1} + w_t)Z_{it} + U_{i,t-1} + \epsilon_{i,t}$ and $S_{i,t-1} = \beta_{t-1}Z_{i,t-1} + U_{i,t-1}$, so that $dS_{i,t} = \beta_{t-1}dZ_{i,t} + w_t Z_{it} + \epsilon_{i,t}$, which decomposes the sovereign proxy change into a term of changed fundamentals, a term of the effect innovation and an unexplained term.

⁴Besides investor sentiment and liquidity factors, these US financial indicators are partly determined by prospects of global fundamentals even though traditional macroeconomic data does not adequately capture this component (see Fülöp and Kocsis, 2018).

$$\log S_{i,t} = \beta'_t Z_{i,t} + \gamma'_i W_t + \alpha_i + u_{it}, \quad (9.3a)$$

where cross-section effects may be included and the disturbance is assumed to exhibit both serial correlation and cross-section dependence. The cross-section dependence will be mitigated by both global financial stress proxies (VIX index or the US High Yield spread) entering W_t or in the most flexible version time effects α_t are included.

The other preferred specification has the first-differenced series as the dependent and the reversion to the (conditional) long-term mean $\beta^l_{t-1} Z_{i,t} + \gamma^l_i W^l_{t-1}$ is explicitly specified. In this specification the cross-section dependence is explicitly handled by estimated common factors with heterogenous (but time-invariant) loadings, $\lambda_{i,j} f_{j,t}$.

The estimation of this model is more demanding than the previous specification and it has several issues regarding identification that are discussed below. It is necessary to keep the model as parsimonious as possible, therefore I assume fairly restrictive short-term effects for fundamentals (i.e only the contemporary change allowed to have an additional effect) and a homogeneous autoregressive process (κ).

$$\Delta \log S_{i,t} = -\kappa(\log S_{i,t-1} - \beta^l_{t-1} Z_{i,t-1} - \gamma^l_{(i)} W^l_{t-1}) + \beta^s \Delta Z_{i,t} + \lambda_{i,j} f_{j,t} + \epsilon_{i,t}, \quad (9.3b)$$

Homogeneity of β is assumed across countries in both preferred specifications, since the focus of interest lies on the cross-section sensitivity of spreads to fundamentals and the fully flexible time-dimensional variation in β would not permit estimating cross-sectional heterogeneity of this parameter anyway.

9.2.2 Estimation methods and identification issues

I use two main estimation methods for the above models. On one hand, for both specifications I use panel LSDV (least squares dummy variables) estimation with various types of standard error estimates and control variables (whether fixed effects or explicit proxies). On the other hand, for the second specification (9.3b), I use state space modelling with an EM algorithm to estimate the latent variable and other parameters.

The panel estimation techniques, given the assumption of no endogeneity (regressors and disturbances being uncorrelated), are consistent and unbiased. However simple OLS estimates of the error variance and hence standard errors are likely to be severely downward biased in our case since OLS assumes independence of observations (controlled for regressor effects), whereas in the current setting disturbances are likely to be both cross-sectionally and serially correlated. Therefore I experiment with both White diagonal standard errors and double clustered standard errors proposed by [Thompson \(2011\)](#).

The specification in (9.3b) explicitly controls for both serial correlation (by first differencing) and cross-section dependence (by controlling for common dynamics, f_t) and thus dis-

turbances can be assumed to be independent. In this case least-squares estimates are optimal (BLUE). Further, using the stylized fact in the previous chapter that log credit spread changes are approximately normally distributed, maximum likelihood estimates are also valid and (asymptotically) these will be optimal in terms of efficiency due to reaching the Cramer-Rao lower bound of errors. This is also important, because the parameters and states of the state space model can then be estimated by the Expectation Maximization method [Dempster, Laird and Rubin \(1977\)](#) that uses the Kalman filter in the Expectation step and OLS estimates in the Maximization step.

To select which estimation methods result in the best tests for assessing time-variation, I set up Monte Carlo simulations to gauge how reliable these methods are in our context.

Identification issues and collinearity

The specification (9.3a) is identified in a straightforward manner. It is only required that regressors not be perfectly collinear, which is only important in the current application at one point: it prevents estimation of global variable effects (e.g the VIX index) together with period effects.

Identification and estimation in (9.3b) is more problematic on several points. (1) Obviously, if there is no mean reversion $\kappa = 0$, then the long-term mean is unidentified. As sovereign credit risk variables are highly persistent, there may be a small amount of information about the long-term mean making inference about β imprecise (large standard errors). Therefore it is difficult to identify time variation in these effects and the null of no-change in effects may be accepted due to the lack of adequate information.

(2) When Z contains a noisy variable where the cross-sectional variation is relevant in terms of sovereign risk (most of the variables that the thesis is concerned with), then inclusion of controls for the cross-sectional variation (e.g. cross section fixed effects) will bias estimates toward zero and will augment standard errors, because the control filters the cross-section dimensional information in the variable leaving behind a larger proportion of cross-sectional noise and the irrelevant time series variation. In the opposite case that Z contains a noisy variable that exhibits strong commonality in its dynamics with relevant impact on sovereign risk, then coefficient estimates are downward biased in absolute value and are inefficient when a proxy for the common variation $\hat{f}_{j,t}$ is included in the model. In this case $\hat{f}_{j,t}$ picks up much of the relevant information of the fundamental leaving the time-dimension noise content next to the reduced fundamental content plus the irrelevant cross-sectional variation of the variable. Noise biases the pooled parameter estimate toward zero and time series estimation (or CX fixed effects) is expected to perform better.

(3) In case that the common risk premium is proxied by period effects, these effects may be difficult to recover if there is already a common factor estimated in f_t , which has nearly uniform loadings. In the nominal spreads settings this is less of an issue, because the common factors have loadings that are highly variable in the cross-section, largely linked to the mean of the credit risk variable. However, in the logarithmic specification the global factor may have

similar loadings in the cross-section.

(4) Multicollinearity is a more important issue in the current case with time-variation allowed in the parameters than in fixed coefficient applications. As well known (Frisch-Waugh-Lovell Theorem), the least squares estimate of a regressor Z_j is based only on the part of the covariance with the dependent that is uncorrelated with other factors in Z . Intuitively, adding a variable of similar content to Z reduces the precision of estimates. This is particularly problematic, when the two variates are really just noisy measures of a real (latent) factor affecting credit risk. In such a case the informative content of these variables are disregarded by least squares and the effect of noise components on the dependent are estimated. Even worse, in the specification (9.3b), the more vague long-term effects are estimated. When two variables are closely related and have very similar effects, estimation breaks down as it is equally valid to assign the reversion target of the dependent to either of the two variables: during the time that the mean reversion takes place the difference between the two effects become indistinguishable.

9.3 Monte Carlo simulations

Many of the estimation methods and tests necessary for the problem at hand require large samples of which the finite sample properties are not known. Therefore it is instructive to see how these methods and tests work in finite samples using a Monte Carlo simulation exercise that replicates some of the already known characteristics of the data generating process and the data sample used.

The exercise involves the following steps:

1. Simulate artificial fundamentals (e.g ratings) and global market shocks paths with properties uncovered in Chapter 8.
2. Using these inputs simulate bond spread and CDS spread data also consistently with properties uncovered in Chapter 8. Simulate these data
 - (a) where the effect of fundamentals are fixed in time
 - (b) where the effect of fundamentals vary in time (in several possible ways).
3. Estimate the link between spreads and fundamentals using various techniques. Identify whether the coefficient has changed based on the given technique.
4. Assess the performance of various techniques: which technique/test is better at estimating the effect and stability of the effect?

The exercise assumes that the dependent credit risk variables Y_{it} (thought of as CDS spreads and FX bond spreads) are observed for a set of 30 countries and 60 time periods for one risk variable (bond spreads) and 50 countries and 40 time periods for the other (CDS spreads). This largely corresponds to the observed quarterly sample.

The changes in the dependent are determined by reversion toward a long-run mean set by two fundamentals $X1_{it}$ and $X2_{it}$ with potentially time-varying effects β_t^1 and β_t^2 , a risk premium variable common to all countries and both risk variables RP_t and country-specific fixed effects α_i . Additionally, the changes in the dependent are influenced by common shocks to the risk premium f_t with loading L_{yi} and country-specific (fundamental shocks) ϵ_{it} and risk variable specific shocks ϵ_{it}^{Y2} .

Fundamentals $X1_{it}$, $X2_{it}$ and RP_t are themselves mean reverting processes, reverting to country-specific means $\tilde{X}1_i$, $\tilde{X}2_i$ and 0, respectively. Fundamentals and risk premia are also subject to common shocks with loadings L_{X1i} , L_{X2i} , L_{RP} , respectively. Fundamentals are also affected by country-specific fundamental shocks that affect Y (ϵ_{it}) and shocks that do not affect Y ($\nu1$, $\nu2$). The scale of country-specific shocks are assumed homogenous across countries. Risk premia shocks have an idiosyncratic component ϵ_t^{RP} next to the common component f_t .

All shocks are assumed independent and normally distributed with variance 0.01 to match scales of log spreads, though shocks ϵ_{it} are additionally scaled by σ_Y and σ_{X1} , σ_{X2} , and shocks $\nu1$, $\nu2$, ϵ_{RP} by Q_{X1} , Q_{X2} , and Q_{RP} , respectively, which are fixed by the parameter-assumption scenarios below.

Cross-section effects are also normally distributed around 4.5 to set Y to values of log credit spreads according to the mean of such series. The variance of cross-section effects is 0.25, whereas X1 and X2 long-run values have variances of 1 so that X1, X2 fundamentals capture a large fraction of the cross-sectional variation in Y (as seen to be true for credit ratings).

Formally, the following equations summarize the data generating assumptions.

$$\begin{aligned}
\Delta Y1_{it} &= -\kappa^Y U1_t + f_t L_{Yi} + \sigma_Y \epsilon_{it} - \epsilon_{it}^{Y2}/2 \\
\Delta Y2_{it} &= -\kappa^Y U2_t + f_t L_{Yi} + \sigma_Y \epsilon_{it} + \epsilon_{it}^{Y2}/2 \\
U1_t &= Y1_{it-1} - \beta1_t X1_{it} - \beta2_t X2_{it} - \alpha_i^1 - RP_t \\
U2_t &= Y2_{it-1} - \beta1_t X1_{it} - \beta2_t X2_{it} - \alpha_i^2 - RP_t \\
\Delta X1_{it} &= -\phi^{X1}(X1_{it-1} - \tilde{X}1_i) + f_t L_{X1} + \sigma_{X1} \epsilon_{it} + Q^{X1} \nu_{it}^1 \\
\Delta X2_{it} &= -\phi^{X2}(X2_{it-1} - \tilde{X}2_i) + f_t L_{X2} + \sigma_{X2} \epsilon_{it} + Q^{X2} \nu_{it}^2 \\
\Delta RP_t &= -\phi^{RP}(RP_{t-1} - 0) + f_t L_{RP} + \sigma_{RP} \epsilon_t^{RP} \\
\alpha_i &\sim N(4.5, 0.25), \quad X1_i \sim U(-6, 6), \quad X2_i \sim N(0, 1) \\
\epsilon_{it}, \epsilon_{it}^{Y2}, \epsilon_t^{RP}, f_t, \nu_{it}^1, \nu_{it}^2, \nu1_{it} &\sim N(0, 0.01);
\end{aligned} \tag{9.4}$$

Parameters of these processes are set to conform with the empirical observations about credit risk variables discussed in the previous chapter. The first fundamental (X1) is assumed to represent slowly changing variables, such as credit ratings or the debt ratio, whose effects are of the main concern for the thesis. As observed by the literature and also in the current data set used, ratings do not account for some of the business cycle fluctuations that are however also determinants of credit risk and credit spreads. Moreover such fluctuations are partly shared across

countries. This type of fundamental is captured by X2.

There are three sets of parameter assumptions used. One corresponds to the benign case of well-observed fundamentals and credit risk spreads that also respond quickly to fundamentals. In the second case, credit spreads adjust to fundamentals slowly and fundamentals are observed via noisy proxies that lag fundamentals. In this case true fundamentals are assumed to follow a much more volatile process, but because only noisy and slowly adjusting, lagged proxies of these fundamentals can be observed, this gives a false sense of slowly changing fundamentals. The third case aims to capture the setting that there are several imperfect proxies of fundamentals, many of which can moreover be correlated with both fundamentals. For instance the debt ratio, external debt to GDP, real GDP growth rates, current account are correlated, lagged and noisy proxies of both a true underlying through-the-cycle default probability and the real business-cycle.

- **Observed fundamentals.** To represent slow changes in X1, $\phi^{X1} = 0.01$, while $\phi^{X2} = 0.1$ to capture faster reversion. RP reversion is also slow ($\phi^{RP} = 0.01$) to represent a close to unit root process. X1 is assumed to represent country-specific fundamentals only with lagged response, so $L_{X1} = \sigma_{X1} = 0$ and $Q_{X1} = \sqrt{3}$. X2 and RP are partly global $L_{X2} = \sqrt{0.5}$, $L_{RP} = \sqrt{0.5}$ and $Q_{X2} = \sqrt{5}$, $\sigma_{X2} = 0$, $\sigma_{RP} = \sqrt{0.5}$. The dependent is assumed to immediately adjust ($\kappa^Y = 1$) consistent with an assumption that markets are efficient and credit spreads (allowing for risk premia and cross-section effects as unobserved heterogeneity) instantly adjust to changes in fundamentals. Fundamentals are thought to be observed, so that $Z1_{it} = X1_{it}$, $Z2_{it} = X2_{it}$ and $ZRP_t = RP_t$.
- **Noisy and lagged proxies.** Reversion to means are relatively quick and identical for X1 and X2 $\phi^{X1} = \phi^{X2} = \sqrt{0.1}$. X1 is still country-specific, $L_{X1} = \sigma_{X1} = \sigma_{X2} = 0$, but highly volatile due to $Q_{X1} = \sqrt{30}$. X2 (rather than RP) provides most of the global variation in spreads by setting $L_{X2} = Q_{X2} = \sqrt{30}$, also a highly volatile process. The process for RP is the same as in the previous case. Z1 and Z2 are noisy and lagged observations. Their process is similarly setup as the fundamental variables with a mean reversion component toward X1 and X2, respectively, of a speed $\kappa^Z = 0.1$ and random shocks of unit variance.
- **Noisy, lagged, correlated proxies.** X1, X2 and RP have the same data generating process as in the 'observed fundamentals' case. There are however six proxies available, Z1-Z6, which revert toward both X1 and X2, causing them to be cross-correlated. Z1, Z3 mean revert toward X1 with parameter 0.1 and toward X2 with parameter 0.01. Z2, Z4 have the same reversion speeds toward X2 and X1. Z5, Z6 revert toward X1, X2 with speed 0.005. Random shocks of proxies have variance set to 10.

Finally, the process for the true β process is assumed to be one of the following four types:

- fixed, time-invariant parameter ($\beta_1 = \beta_2 = 0.4$).

- crisis-dependent (setting β_1 to 0.5 for a 10-period crisis and 0.3 for all other, non-crisis periods).
- risk premium dependent (β of both fundamentals reverts to long-term value of 0.4 with speed ϕ^{RP} ; fundamentals are also shocked by f_t with loadings 0.4 and 0.8, respectively – these settings ensure a process weakly cross-correlated and unit-root-like for X1 and more volatile, mean reverting and more cross-correlated process for X2).
- close-to-random walk process (innovations $\sim iid N(0, 0.1)$ and reversion parameter 0.1 with long-run value of 0.4).

For each of the three parameter settings and the four β assumptions 100 simulations are generated for latent fundamentals, latent risk premia, their observed proxies and the credit spread dependent variables.

Table 9.1: Estimated model specifications

Model spec.	Dependent		Controls		Estim.method	Std.errors
		ZRP_t	CX eff.	Time eff.		
Levels 1	Y				pooled OLS	simple
Levels 2	Y	x	x		panel LSDV	White diagonal
Levels 3	Y		x	x	panel LSDV	White diagonal
Levels 4	Y	x			pooled OLS	double robust
Levels 5	Y			x	panel LSDV	double robust
Diffs 6	dYi	x	x		panel LSDV	White diagonal
Diffs 7	dYi				pooled OLS	White diagonal
Diffs 8	dY	x			pooled OLS	double robust
Diffs 9	dY				pooled OLS	double robust
Diffs 10	dY	x	x		panel LSDV	White diagonal
EM 11	dY	x			EM algorithm	state variance
EM 12	dY			x	EM algorithm	state variance
EM 13	dYi	x			EM algorithm	state variance
EM 14	dYi			x	EM algorithm	state variance
EM 15	dYi	x	x		EM algorithm	state variance
EM 16	dYi		x	x	EM algorithm	state variance
EM 17	Y				EM algorithm	state variance
EM 18	Y	x			EM algorithm	state variance
EM 19	Y			x	EM algorithm	state variance
EM 20	Y		x		EM algorithm	state variance
EM 21	Y		x	x	EM algorithm	state variance

Sources: author calculations.

Notes: The table reports specifications used for estimation. The dependent takes the levels form, differenced form or differenced form with the first principal components extracted (Y/dY/dYi). Controls are the proxy for the risk premium (ZRP_t), cross-section fixed effects and/or time fixed effects (models without fixed effects have a constant included).

Several different model specifications are then estimated, Table 9.1 lists 21 of these that were used for the first two parameter sets. These specifications differ by the assumed functional

form of the dependent (levels or first differences), the included controls (fixed effects and/or risk premia variables) and the estimation technique as described in the previous section. Specifications are estimated both with the inclusion and omission of the Z_2 proxy for the 'observed fundamentals' and 'noisy proxies' cases. For the 'correlated noisy proxies' case only 6 selected specifications (Levels 2-5 and EM 13, EM 19) have been used, but for these cases Cholesky-based, PCA-based and Procrustes factorization-based handling of the multicollinearity problem are also investigated.

9.3.1 Monte Carlo results

For being able to answer the hypotheses, the crucial question to answer is which type of test and which model specification is the best to use to decide whether the effect β_1 is time-varying or not. Since the hypotheses are setup with the null of no time-variation in effects, the size (Type I error) of tests are of primary importance, i.e when a test erroneously rejects the null proposing time-variation when in fact the effect is time-invariant. Of lesser importance, but still of interest is the power of tests (Type II error rate), i.e the erroneous acceptance of the null of no time-variation when in fact the effect is time-varying.

Out of the 21 specifications, four levels, panel estimated specifications Levels 2-5, two quasi-differenced panel-estimated specifications (Diffs 7 CR,RP) and two EM-estimated state space specifications (EM 13 and 19) are selected to work with in the rest of the thesis. The primary basis for selecting these specifications is that they (especially Levels 4-5 and somewhat Diffs 7, Levels 2-3) tend to perform best in terms of testing the time-variation of fundamental effects.

Regarding the F-test (F-tests have the best size properties out of various testing procedures as shown in Appendix Table C.3), many of the other specifications have a problem of low size, i.e they overreject the null hypothesis (proposing time-variance when the true β coefficient is fixed). This is especially relevant in the cases, when fundamentals are not perfectly observed (Appendix Tables C.5 and C.6). Power against the alternatives considered (erroneously rejecting time-variance) is less of an issue as rejection rates of the time-invariant null are adequately high in most specifications, including the ones selected here. Finally, the specifications which have the dependent variable in levels (and especially Levels 4-5 and EM 19) provide a good estimate of the parameter β in terms of RMSE under various parameter settings (Tables C.7-C.9) and also have a low error when estimating the cross-sectional variance share of the X1 fundamental (Table C.10). In contrast, the first-differenced specifications tend to have much poorer RMSE statistics both in terms of β and estimated variance shares.

Table 9.2 provides F-test statistics for the 7 selected model specifications. This constitutes the main results of the Monte Carlo exercise.

Based on Table 9.2, there are significant differences in the performance of various tests and model specifications with respect to whether proxies of fundamentals are noisy or not (Panels A

Table 9.2: F-test rejection rates of time-invariant effects (MC simulations)

		Z_2 in model:				Z_2 omitted			
		TRUE β :	Z_2 included				Z_2 omitted		
Modelled $\hat{\beta}$	Model spec.		β_0	β_C	β_{RP_t}	β_t	β_0	β_C	β_{RP_t}
PANEL A: Observed fundamentals									
period	Levels 2		0.000	1.000	1.000	1.000	0.450	1.000	1.000
period	Levels 3		0.000	1.000	1.000	1.000	0.520	1.000	1.000
period	Levels 4		0.000	1.000	1.000	1.000	0.000	1.000	1.000
period	Levels 5		0.000	1.000	1.000	1.000	0.000	1.000	1.000
crisis	Diffs 7		0.070	1.000	0.250	0.990	0.080	1.000	0.360
RP	Diffs 7		0.210	0.740	0.970	0.920	0.030	0.550	0.360
PANEL B: Noisy fundamental proxies									
period	Levels 2		0.980	1.000	1.000	1.000	0.450	1.000	1.000
period	Levels 3		0.620	1.000	1.000	1.000	0.450	1.000	1.000
period	Levels 4		0.130	0.980	1.000	1.000	0.030	0.800	1.000
period	Levels 5		0.000	0.960	1.000	1.000	0.000	0.790	1.000
crisis	Diffs 7		0.100	1.000	0.970	1.000	0.110	1.000	0.980
RP	Diffs 7		0.120	0.580	0.910	0.830	0.070	0.570	0.600
PANEL C: Correlated noisy fundamental proxies									
period	Levels 2		0.860	1.000	1.000	1.000	0.520	1.000	1.000
period	Levels 3		0.850	1.000	1.000	1.000	0.550	1.000	1.000
period	Levels 4		0.790	1.000	1.000	1.000	0.030	0.970	0.990
period	Levels 5		0.800	1.000	1.000	1.000	0.040	0.970	1.000

Sources: author calculations.

Notes: The table reports rejection rates of the null hypothesis that β , the effect of X_1 on the dependent, is time-invariant on Monte Carlo simulated data (100 simulations). The F-test is used at 5 percent significance levels. These rates correspond to the size of the test (Type I errors) when the true β is time-invariant (β_0 columns) and the power of the test (Type II error) when the alternative hypothesis of time-variant β is true (β_C : level shift of effect in crisis; β_{RP_t} : effect dependent on Risk Premium; β_t : effect following a random walk). An efficient test therefore has close to 0 rejection rates in β_0 columns and close to 1 rejection rates in other columns.

The left and right panels of the table differ based on whether Z_2 , the proxy for the fundamental X_2 is included or excluded from the model. Panel A and B differ based on whether the fundamentals are perfectly observed by proxies ($X_1 = Z_1$, $X_2 = Z_2$) or the proxies contain noise. Rows of the table within panels correspond to different model specifications given by the first two columns. In Panel C, no omission includes all 6 (Z_1 - Z_6) proxies and omission only includes Z_1 .

and B) and whether Z_2 is included or omitted. When fundamentals are observed and Z_2 is *omitted* (!) levels specifications appear to be perfect separators of time-variance/-invariance of the β_1 effect, never rejecting time-invariance when the true effect is fixed (β_0 columns) and always rejecting time-invariance for the considered three alternatives (columns β_C , β_{RP} , β_t). However when Z_2 is included in the model, the Levels 2 and Levels 3 specifications (that includes cross-section fixed effects) overreject the null proposing time-variance when the true effect is time-invariant. The Levels 4 and 5 specifications, which do not include cross-section fixed effects remain perfect separators. The crisis-dummy version of the first difference specification (Diffs 7, which also does not include fixed effects) appears to be a good test of time-variation in both cases.

When proxies are noisy, overrejection of the null becomes even greater as F-tests at the 5 percent significance reject the null hypothesis at a higher rate. The model specification with period-dependent $\hat{\beta}_t$ and the Levels 5 specification appears robust to these changes and the Levels 4 and the Diffs 7 specifications are second-best in terms of test size.

For the correlated proxies case, the Levels 4-5 specifications are again much better than the Levels 2-3, moreover inclusion of all relevant fundamental proxies (Z_2 - Z_6 under this settings) leads to inferior size (significant overrejection) compared to the omission case, when only Z_1 is included.

Most of the selected specifications are fairly good at accepting the alternatives (rejecting

the null), when the alternatives are true regardless of the parameter settings and the true β alternatives.

Table 9.3: RMSE of X_1 effect estimates on the dependent (MC simulations)

Z_2 in model:		Z_2 included				Z_2 omitted			
TRUE β :		β_0	β_C	βRP_t	β_t	β_0	β_C	βRP_t	β_t
Modelled $\hat{\beta}$	Model spec.								
PANEL A: Observed fundamentals									
period	Levels 2	0.118	0.127	0.204	0.142	0.117	0.129	0.214	0.142
period	Levels 3	0.117	0.126	0.205	0.141	0.116	0.127	0.211	0.143
period	Levels 4	0.048	0.033	0.060	0.029	0.053	0.043	0.065	0.038
period	Levels 5	0.049	0.033	0.060	0.029	0.053	0.043	0.065	0.038
crisis	Diff 7	0.085	0.106	0.685	0.172	0.110	0.274	12.070	0.261
RP	Diff 7	0.064	0.200	0.242	0.181	0.082	0.514	109.359	0.265
RW	EM 13	0.073	0.049	0.102	0.074	0.075	0.117	8.806	0.052
RW	EM 19	0.046	0.032	0.062	0.028	0.047	0.041	0.086	0.036
PANEL B: Noisy fundamental proxies									
period	Levels 2	0.139	0.127	0.204	0.142	0.139	0.129	0.214	0.142
period	Levels 3	0.139	0.126	0.205	0.141	0.138	0.127	0.211	0.143
period	Levels 4	0.025	0.033	0.060	0.029	0.031	0.043	0.065	0.038
period	Levels 5	0.025	0.033	0.060	0.029	0.032	0.043	0.065	0.038
crisis	Diff 7	0.035	0.106	0.685	0.172	0.053	0.274	12.070	0.261
RP	Diff 7	0.034	0.200	0.242	0.181	0.050	0.514	109.359	0.265
RW	EM 13	0.066	0.049	0.102	0.074	0.087	0.117	8.806	0.052
RW	EM 19	0.025	0.032	0.062	0.028	0.029	0.041	0.086	0.036
PANEL C: Correlated noisy fundamental proxies									
period	Levels 2	0.384	0.332	0.542	0.410	0.383	0.331	0.543	0.409
period	Levels 3	0.384	0.331	0.542	0.410	0.383	0.331	0.543	0.409
period	Levels 4	0.219	0.192	0.308	0.232	0.095	0.081	0.127	0.098
period	Levels 5	0.218	0.190	0.307	0.231	0.094	0.080	0.124	0.096
RW	EM 13	0.281	1.208	0.722	0.297	0.193	0.855	3.194	11.259
RW	EM 19	0.211	0.184	0.289	0.220	0.091	0.086	0.125	0.090

Sources: author calculations.

Notes: The table reports root mean squared error of $\hat{\beta}^{X_1}$ compared to the true effect, β^{X_1} , in Monte Carlo simulations (100 simulations). See Table 9.2 notes for column, row and panel definitions.

Table 9.3 turns to the issue of how well model estimations are able to recover the true effects. This issue is related to, but distinct from the previous issue of assessing time-variation in the effect. Although a lack of fit to the true effect makes it impossible to discern whether the true effect is varying or not in time, a fair model fit does not necessarily result in a proper evaluation of time-variance. For instance a method that results in a very good point estimate of the effect but an overconfident (underestimated) error of the model would more often result in rejecting time-invariance, as it accepts chance variation in the estimated effect as true variation.

The specifications Levels 4 and 5 stand out as ones robust to noise of proxies and specification regarding inclusion/exclusion of Z_2 . Other specifications have RMSE significantly rising as the proxies become noisy. Interestingly, nearly all specifications have a slightly worse fit when Z_2 is included compared to when it is omitted. The RMSE advantage of Levels 4 and 5 (no cross-section effects) over Levels 2 and 3 (with cross-section effects) in most cases and the advantage of Diff 7 (no cross section effects) over other specifications with fixed effects, suggests that omission of Z_2 and cross-section effects (even though they are by design relevant for the dependent) results in a better assessment of the effect of Z_1 . This deterioration of fit occurs due to correlations between Z_1 and Z_2 , fixed effects, which are known to be chance correlations by design in this case.

Table 9.4: RMSE of X_1 estimated cross-section variance share (MC simulations)

Z_2 in model:		Z_2 included				Z_2 omitted			
Modelled $\hat{\beta}$	TRUE β :	β_0	β_C	βRP_t	β_t	β_0	β_C	βRP_t	β_t
	Model spec.								
PANEL A: Observed fundamentals									
period	Levels 2	0.007	0.010	0.010	0.008	0.007	0.010	0.010	0.008
period	Levels 3	0.007	0.010	0.010	0.008	0.007	0.010	0.010	0.008
period	Levels 4	0.007	0.010	0.010	0.008	0.007	0.010	0.010	0.008
period	Levels 5	0.007	0.010	0.010	0.008	0.007	0.010	0.010	0.008
crisis	Diff 7	0.007	0.010	0.011	0.008	0.007	0.010	1.457	0.008
RP	Diff 7	0.007	0.010	0.010	0.008	0.007	0.010	0.719	0.008
RW	EM 13	0.007	0.010	0.010	0.008	0.007	0.010	0.760	0.008
RW	EM 19	0.007	0.010	0.010	0.008	0.007	0.010	0.010	0.008
PANEL B: Noisy fundamental proxies									
period	Levels 2	0.008	0.010	0.010	0.008	0.008	0.010	0.010	0.008
period	Levels 3	0.008	0.010	0.010	0.008	0.008	0.010	0.010	0.008
period	Levels 4	0.008	0.010	0.010	0.008	0.008	0.010	0.010	0.008
period	Levels 5	0.008	0.010	0.010	0.008	0.008	0.010	0.010	0.008
crisis	Diff 7	0.008	0.010	0.011	0.008	0.009	0.010	1.457	0.008
RP	Diff 7	0.008	0.010	0.010	0.008	0.009	0.010	0.719	0.008
RW	EM 13	0.008	0.010	0.010	0.008	0.008	0.010	0.760	0.008
RW	EM 19	0.008	0.010	0.010	0.008	0.008	0.010	0.010	0.008
PANEL C: Correlated noisy fundamental proxies									
period	Levels 2	0.229	0.689	0.858	0.770	0.108	0.636	0.887	0.709
period	Levels 3	0.222	0.654	0.868	0.751	0.117	0.609	0.913	0.702
period	Levels 4	0.030	0.023	0.032	0.020	0.028	0.022	0.029	0.018
period	Levels 5	0.030	0.023	0.032	0.020	0.028	0.022	0.029	0.018
RW	EM 13	0.193	0.047	0.360	0.078	0.169	0.043	0.496	0.074
RW	EM 19	0.029	0.022	0.030	0.018	0.028	0.022	0.030	0.018

Sources: author calculations.

Notes: The table reports root mean squared error of the estimated ratio of the cross-sectional variance explained by X_1 compared to the variance share in Monte Carlo simulations (100 simulations). See Table 9.2 notes for column, row and panel definitions.

9.3.2 Implications of the exercise

These results suggest to estimate models Levels 4 and 5 to assess the null hypothesis using the F-test. Under the each of the parameter settings ('observed fundamentals', 'noisy proxies', 'correlated noisy proxies') of the assumed data generating process F-tests on these specifications appear to correctly accept time-invariance when time-invariance is true and correctly reject time-invariance in the three considered alternatives. Both use panel estimates of the dependent in levels with period-specific effects for the fundamental. Neither specifications include cross-section fixed effects (as opposed to Levels 2-3). The difference between the two specifications relates to how the effect of risk premia is controlled. Levels 4 uses the proxy for risk premia, whereas Levels 5 uses period fixed effects.

Other specifications are less robust, but may constitute useful cross-checks of the Levels 4 and Levels 5 verdicts. The Diff 7 is useful, when the true β is time-invariant, because (in contrast to most other specifications) Diff 7 also rarely rejects the null in these cases. Thus, when Levels 4 and 5 accept time-invariance, Diff 7 specifications could be used to see whether these also support time-invariance. (However, when Levels 4 - 5 reject, Diff 7 is less relevant as it tends to perform poorly against alternatives.)

If on the other hand, the Levels 4 and 5 reject time-invariance, then Levels 2 and Levels 3 could be used to cross-check rejection. These specifications are also powerful against alternatives considered in the exercise, therefore they would also tend to reject the null, when the effect

is time-varying. (The converse is not true: when Levels 4-5 accept time-invariance, Levels 2-3 are not useful cross-checks as they tend to erroneously overreject the null.)

For estimates of the effect and assessment of the variance share attributed to fundamentals the Levels 4-5 and EM 19 models are best to use, because these are shown to provide best estimates that are also robust under various scenarios. Because the choice of risk premium proxies is somewhat ad hoc (VIX index, High yield spreads), Levels 5 and EM 19 are more straight-forward in practice and are preferred over Levels 4.

CHAPTER 10

Results

This chapter first assesses the hypotheses regarding time-variance of the pricing of fundamentals within sovereign credit spreads. The tests and specifications used rely on the conclusions of the preliminary empirical analysis in Chapter 8 and Monte Carlo simulations in Chapter 9 and Appendix C.3. This prior work was necessary to reduce the large set of possible specifications (used by the empirical literature) to those, which tend to provide the best estimates of fundamental effects in the cross-section and which can best distinguish between time-variation and time-stability of these effects.

The first section assesses time-variation in the estimated effects based on F-tests and states the main theses based on this analysis. The section then characterizes the evolution of rating effects and the fundamental variance share over the time sample. The second half of the section investigates possible explanations for the findings.

The second part of the chapter turns to the time-variation of the debt ratio (the public debt to GDP measure) in sovereign risk pricing. After stating the related thesis, the section studies the background of the observed time-variation.

Regarding the data used, the first section primarily relies on CDS spreads (54 countries Jan 2007 - Jun 2016), EMBI bond spreads (10 countries Jan 1999 - Nov 2017), eurozone yield spreads to Bund (10 countries Jan 1999 - Nov 2017) and ratings data (60 countries: all which have either of CDS or bond spreads, Jan 1999 - Nov 2017) sourced from Bloomberg and Reuters. Parts of this section and the second section also uses macroeconomic data of the same set of countries in the Jan 1999 - June 2016 period from mainly the World Bank and the IMF. See Appendix A.1 for more details.

10.1 Time-variation in the pricing of fundamentals

To assess whether the pricing of fundamentals in credit spreads have changed over time, I first use credit ratings as proxies for fundamentals. Credit ratings are arguably the best single aggregate variables of domestic fundamentals related credit risk as they collect information on many domestic fundamental aspects relevant in this respect. Ratings are a cheap source of credit risk information, which is likely to be used by many market participants and therefore the information they aggregate is likely to influence prices. As argued before, the rating scale does achieve its main purpose of ranking countries by their probability of default and there is a clear (cross-sectional) empirical relationship between ratings and spreads.

Ratings, however, do not account for all aspects of sovereign credit risks that investors face. Ratings are set with a long-term (through-the-cycle) view, therefore components due to

domestic real activity are not addressed. Ratings do not account for contagion, liquidity risks and other purely external shocks that influence default risk as well, and they do not inform of expected haircuts in case of a default. Ratings are also a lagged measure of risk and they include a calculable persistence that investors are likely to take into account. Due to these factors, ratings align well with credit spreads in the cross-section dimension, but the time series relationship of the two measures is less straight-forward to model.

Chapter 8 showed that there is a close to linear empirical relationship between ratings and logarithmic CDS and logarithmic bond spreads (EMBI and yield differences to the Bund) in the cross-section dimension, but the levels of spreads are also influenced by (volatile) shocks common to the full cross-section. The log specification for spreads (unlike the linear, basis points specification) have loadings on the global component that are similar across countries, therefore the effects of the global factor can plausibly be proxied by shifts in the mean of the cross-section. Further, logarithmic spread changes on the quarterly frequency are close to being normally distributed.

Other than credit ratings, I also consider two specifications that include many of the most commonly used fundamental proxies in the empirical literature as discussed in Chapter 4 and a specification that incorporates both ratings and a series of fundamental proxies (as [Cantor and Packer, 1996](#), and many subsequent papers have done). These proxies include real GDP growth, fiscal and current account balances, the debt ratio, reserves, inflation, per capita GDP, and World Governance Indices to proxy political stability and institutional background. Two other specifications include variables based on the theoretical analysis in Chapters 5 and 6, in particular, domestic government debt interacted with private credit (governments with large domestic debt and large financial sectors were argued to fear default due to its impact on the economy), external government debt (this is important via an interaction with trend growth and real interest rate and also from a funding liquidity perspective to the extent that external debt well-proxies foreign currency debt) and debt interactions with WGI indicators (governments with weaker institutions and political stability were argued to be more prone to default with larger debt amounts).

Chapter 9 showed that, given a data generating process and data availability similar to the current context, the best model specifications to use are the panel levels specifications given by equations (9.3a) with controls of the common global component either via time fixed effects ('Levels 5') or a risk premium proxy such as the VIX index ('Levels 4'):

$$\begin{aligned}\log S_{i,t,s} &= \beta'_t Z_{i,t} + \gamma_t + \zeta 1_{s=CDS} + u_{i,t,s}, \\ \log S_{i,t,s} &= \beta'_t Z_{i,t} + \gamma VIX_t + \zeta 1_{s=CDS} + u_{i,t,s}.\end{aligned}\tag{10.1}$$

Log spreads are determined in these models by a vector of fundamental proxies Z (of size $K \times 1$) with period-specific coefficients β_t (also size $K \times 1$), which may include ratings, GDP growth rate, the debt ratio, reserves, etc. The second terms of the equations are the mentioned

controls of global time-series variation within spreads. To exploit the information in both credit spread indicators, I stack CDS spreads on bond spreads and use a dummy variable and its effect ζ to allow for a constant difference between the two spread types. The disturbance terms are assumed to be mean zero, iid random variates with correlations allowed across cross-section units and in time, i.e. standard errors are estimated by the double-robust method of [Thompson \(2011\)](#).

I also estimate a state space version of this model ('EMalgo 19'), which restricts the β_t process to be a random walk. In this model the measurement equation is (10.1) and the state dynamics are given by:

$$\beta_t = \beta_{t-1} + \nu_t, \quad \nu_t \sim N(0, Q), \quad (10.2)$$

with Q the covariance of innovations. The state innovations, ν_t are normally distributed, but correlations are allowed. However, in this setup, the measurement equation disturbance, u_{its} are assumed to be independent and also normally distributed, though heteroskedasticity is allowed. Under this setting a Kalman-filter can be used to estimate the expectation and variance of β_t and the EM algorithm is used to estimate parameters of the model iteratively.

Note that none of these specifications include cross-section fixed effects. Specifications with fixed effects (Levels 2, 3 analogous to 4 and 5) are still used in parts of this chapter, but are not preferred, because in a setting where proxies are lagged and observations of persistent fundamentals are noisy (which is arguably the current case with ratings) these specifications tend to both imprecisely estimate fundamental effects and overreject time-invariance as shown in Chapter 9.

Table 10.1 reports F-tests that assess time-variation of fundamental effects on sovereign spreads. Several specifications are considered both where ratings are the key proxy (Panel A) and where several other fundamental variables jointly proxy fundamental effects.

In all cases, the tests strongly reject time-invariance and favoring the alternative hypothesis of Hypothesis 1a and 1b.¹ These results lead to the following statements:

Thesis 1a. *(Fundamental effects) The hypothesis that the pricing effect of country fundamentals in sovereign credit spreads is stable in time is rejected.*

Thesis 1b. *(Fundamental effects (log spread)) The hypothesis that the pricing effect of country fundamentals in the logarithm of sovereign credit spreads is stable in time is rejected.*

¹As reviewed in the last chapter, F-tests perform best out of a group of statistical tests and decision rules. The 'Levels 4' and 'Levels 5' specifications with period effects are a conservative choice for the assessment of the null: with these estimated specifications F-tests rarely reject time-invariance when time-invariance is true and when they do, other specifications appear to reject more often.

Table 10.1: F-tests of fundamental effect time-variance

Model specification	F-test for Spreads				F-test for Log Spreads			
	F-stat	ν_1	ν_2	p-value	F-stat	ν_1	ν_2	p-value
PANEL A: Fundamentals measured by ratings								
Levels 5	6.639	60	3938	0.000	7.284	60	3938	0.000
Levels 5a	10.058	180	3938	0.000	4.783	180	3938	0.000
Levels 5b	8.073	240	3595	0.000	3.514	240	3595	0.000
Levels 4	6.595	60	3938	0.000	7.960	60	3938	0.000
Levels 2	7.113	60	3938	0.000	11.786	60	3938	0.000
Levels 3	7.280	60	3938	0.000	9.280	60	3938	0.000
PANEL B: Fundamentals based on multiple proxies								
Emp Lit 1	4.696	329	2905	0.000	3.727	329	2905	0.000
Emp Lit 2	3.865	423	2913	0.000	3.222	423	2913	0.000
RAT + Emp Lit 2	4.447	470	2913	0.000	3.646	470	2913	0.000
Theory 1	6.725	376	2743	0.000	3.486	376	2743	0.000
Theory 2	6.912	282	2743	0.000	3.731	282	2743	0.000

Sources: author calculations.

Notes: The table reports F-tests for parameter restrictions regarding time-variation of fundamental coefficients within regressions of sovereign spreads (left panel) and the logarithm of sovereign spreads (right panel). The F-tests estimate unrestricted models with period-specific coefficients and restricted models with fixed coefficients and assess whether the data support the case for the restriction (time-invariance). Panel A estimates restrictions for only the credit rating level variable (Levels 2,3,4,5) which differ in including period effects/VIX index and cross-section effects. Levels 5a also includes the rating changes in the past two quarters and its lag and (5b) includes also real GDP growth rate in the potentially time-varying set. Panel B turns to 'Levels 5'-type model setup with inclusion of the following variables: Emp Lit 1: debt ratio, real GDP growth, reserves to GDP, current account to GDP, fiscal balance to GDP, GDP per capita in all 'Emp Lit' specifications and additionally: CPI yoy (Emp Lit1); WGI indices of political stability, corruption, rule of law (Emp Lit 2 and RAT + Emp Lit) and ratings (RAT + Emp Lit). The Theory 1 specification includes the debt ratio interacted with credit to gdp, external government debt to GDP, reserves to GDP, current account to GDP, WGI rule of law and political stability, corruption and the debt ratio interacted with the latter two indices. Theory 2 is more parsimonious in that it adds up and includes as single variables: reserves and current account; political stability and government effectiveness; corruption and rule of law; and only includes debt ratio interaction with corruption. Theory 2 also includes the domestic debt and external debt variables.

10.1.1 Credit spread sensitivity to ratings

Figure 10.1 displays the time series of estimated credit rating coefficients. In all specifications there was a notable decline in the period 2002-2006 and a temporary increase in the effects during the financial crisis period (2007-2008). The rating effect estimates declined again as the financial crisis receded and there was an eventual increase in the effect at the end of the period. The specifications that proxy global risk premium shocks to credit spreads via the VIX index (Levels 2 and 4) show a shorter decline of the effect after the financial crisis, already increasing during 2011 and 2012. All other specifications are more flexible (and therefore preferred over the previous specifications) as they proxy shocks by time fixed effects.

Although the verdict of F-tests and Figure 10.1 is unambiguous about time-variation no matter which specification is chosen, coefficients have not displayed changes in orders of magnitude. Moreover the differences among model specification of the effects are comparable to the scale of these changes.

Time-variance in the estimated coefficients could both be due to significant variation within subperiods or across subperiods. Table 10.2 turns to statistical testing of these possibilities. The differences of rating coefficients across four subperiods: (I) pre-crisis (before 2007); (II) financial crisis (2007-2009); (III) sovereign crisis (2010-2012); and (IV) post-crisis (after 2012) are considered. Unlike the F-tests (that test period-specific coefficient stability) these results hinge on the definitions of subperiods. To allow for departures from normality and to use a

Figure 10.1: Time series of estimated rating effects (log spreads)

Sources: author's compilation.

Notes: The figure depicts the time-varying rating coefficients in a variety of log spread model specifications. 'Lev5g' is the 'Levels 5b' specification in Table 10.1 and EM19g is the measurement specification in the state space model. EM19 corresponds to the 'Levels 5' measurement. See Table 10.1 for information on other specifications.

Table 10.2: Kruskal-Wallis tests: rating effect differences across periods

		Specifications (log SPREADS)					
subperiod	statistics	Levels 5	Levels 5a	Levels 5b	Levels 2	Levels 3	Levels 4
PANEL A: Point estimate statistics within period							
Pre-crisis (1)	mean	0.181	0.184	0.196	0.188	0.201	0.215
Financial crisis (2)	mean	0.167	0.164	0.167	0.171	0.197	0.194
Sovereign crisis (3)	mean	0.147	0.147	0.141	0.195	0.220	0.162
Post-crisis(4)	mean	0.196	0.185	0.189	0.183	0.209	0.205
Pre-crisis (1)	stdev	0.029	0.031	0.032	0.021	0.018	0.028
Financial crisis (2)	stdev	0.033	0.033	0.032	0.022	0.025	0.027
Sovereign crisis (3)	stdev	0.016	0.016	0.015	0.020	0.019	0.014
Post-crisis(4)	stdev	0.020	0.011	0.015	0.012	0.012	0.013
PANEL B: Kruskal-Wallis Tests of equality across periods (p-values)							
Equal medians	KW 1-4	0.000	0.000	0.000	0.069	0.023	0.000
No break at (3)	KW 1-2 vs 3-4	0.174	0.051	0.013	0.368	0.006	0.002
Crises not diff't	KW 1-4 vs 2-3	0.000	0.000	0.000	0.360	0.469	0.000
Fin.cris. not diff't	KW 1-3-4 vs 2	0.261	0.336	0.345	0.014	0.082	0.537
Sov.cris. not diff't	KW 1-2-4 vs 3	0.000	0.000	0.000	0.179	0.009	0.000
Post-crises not diff't	KW 2-3 vs 4	0.000	0.001	0.000	0.550	0.016	0.000
Post-sov.cr. not diff't	KW 3 vs 4	0.000	0.000	0.000	0.290	0.592	0.000

Sources: author calculations.

Notes: The upper panel of the table reports of within-subperiod means and standard deviations of estimated coefficients of credit ratings. The lower panel reports p-values of Kruskal-Wallis tests, which have the null hypothesis that medians of these subperiod estimates are equal across subperiods. See the main text and notes in Table 10.1 for information on specifications.

more robust measure, Kruskal-Wallis tests are carried out instead of ANOVA. Kruskal-Wallis tests have the null that all groups have equal medians with the assumption of independence of

observations and identical shape of the distribution.²

The results of the test show that there was considerable cross-period variation in rating coefficients in all specifications, also when forming various alternative groups of subperiods. There are two of seven subperiod groups where the tests accept equality of subsample medians: there was no break in the time series on the turn of 2009-2010 and the coefficients estimated in the financial crisis period have not statistically differed from all other subperiods joined together.

10.1.2 Variance decomposition

Next, I turn to another aspect of the importance of fundamentals in sovereign debt pricing: the share of the cross-sectional variation in spreads that can be attributed to domestic fundamentals. Though related to effect size assessed before, the key difference is that it is a relative effect studied here, as variance share controls for the changes in the cross-sectional variance of spreads.

Figure 10.2: Time series of variance shares explained by fundamentals

Sources: author's compilation.

Notes: The figure assesses the time-varying variance shares attributed to fundamentals in spread and log spread regressions. Black dashed line represents the 'Levels 5b' (Rating + real GDP growth model), black circles represent the richer 'RAT + Emp Lit 2' specification that includes the usual macroeconomic variables in the literature (see Table 10.1 for information on specifications). The blue dashed line and circles display the 'Emp Lit 2' and 'Emp Lit 1' specifications. The magenta dashed line and circles represent variance share of fundamentals in the 'Theory 1' and 'Theory 2' specifications, respectively. Dots correspond to estimates due to bootstrapped cross-section samples.

Figure 10.2 plots how estimated fundamental variance shares changed over time under a battery of specifications. Both the left-hand subplot of the spread and right-hand plot of log spread specifications assess six types of models: two types of models where ratings proxy fundamentals, two models based on the empirical literature and two models based on the theoretical models of the thesis.

Superiority of ratings models (even the parsimonious ratings + real growth specification) to use as proxies of fundamentals is clear from each of these plots as these models can account for a significantly larger variance share compared to models with macrovariables acting as proxies.

²Without recourse to the distribution shape assumption, Kruskal-Wallis tests stochastic dominance, i.e. that based on ranking observations from smallest to largest, no groups have rankings systematically larger than others.

Interestingly, in the log spread specifications there is only a slight increment in explanatory power when macrovariables proposed by the empirical literature are added to the parsimonious model with ratings and real growth. In contrast, macrovariables have a much larger incremental explanatory power in the basis points spread specifications, where the parsimonious rating model has a poor fit. The reason could be the effect of the mentioned misspecification: since ratings are more robustly linked to log spreads instead of linear spreads (spreads in basis points), models that regress ratings on linear spreads provide a worse fit. Then, there is more scope for the residual to be explained by correlations with other macrovariables, especially those, which are correlated with the rating spectrum.

Besides main estimates (dashed line and circles) the plots also show bootstrap results (re-sampling the cross-section), which was argued to be important when assessing the empirical literature: sample selection could greatly influence results. This is confirmed for most specifications, but again in case of log spreads and ratings, sample selection seems to be less of an issue.

It is also clear from Figure 10.2 that the log specification of spreads leads to more robust estimates of the variance share both in the time series (time series of variance shares are less volatile) and in the cross-section dimensions (suggested by the smaller dispersion of bootstrap samples).

Table 10.3: Kruskal-Wallis tests: fundamental variance shares across periods

subperiod	statistics	Specifications					
		Levels 5	Levels 5a	Levels 5b	Levels 2	Levels 3	Levels 4
PANEL A: Point estimate statistics within period							
Pre-crisis (1)	mean	0.922	0.882	0.854	0.781	0.568	0.628
Financial crisis (2)	mean	0.812	0.822	0.679	0.686	0.589	0.604
Sovereign crisis (3)	mean	0.724	0.763	0.482	0.532	0.542	0.520
Post-crisis(4)	mean	0.811	0.815	0.621	0.603	0.564	0.618
Pre-crisis (1)	stdev	0.027	0.087	0.082	0.126	0.132	0.109
Financial crisis (2)	stdev	0.074	0.083	0.118	0.098	0.114	0.117
Sovereign crisis (3)	stdev	0.066	0.067	0.097	0.075	0.070	0.063
Post-crisis(4)	stdev	0.027	0.024	0.052	0.044	0.082	0.073
PANEL B: Kruskal-Wallis Tests of equality across periods (p-values)							
Equal medians	KW 1-4	0.000	0.002	0.000	0.000	0.904	0.015
No break at (3)	KW 1-2 vs 3-4	0.000	0.002	0.000	0.000	0.550	0.161
Crises not diff't	KW 1-4 vs 2-3	0.000	0.015	0.000	0.020	0.951	0.012
Fin.cris. not diff't	KW 1-3-4 vs 2	0.505	0.849	0.721	0.060	0.520	0.830
Sov.cris. not diff't	KW 1-2-4 vs 3	0.000	0.003	0.000	0.000	0.568	0.002
Post-crises not diff't	KW 2-3 vs 4	0.868	0.617	0.739	0.225	0.905	0.134
Post-sov.cr. not diff't	KW 3 vs 4	0.000	0.003	0.000	0.000	0.805	0.007

Sources: author calculations.

Notes: The upper panel of the table reports of within-subperiod means and standard deviations of estimated variance share of fundamental variables in various models. The lower panel reports p-values of Kruskal-Wallis tests, which have the null hypothesis that medians of these subperiod estimates are equal across subperiods. See the main text and notes in Table 10.1 for information on specifications.

Nonetheless there is material time-variation in the variance share attributed to fundamentals even in the log spread specifications based on all model specifications. This is attested by Kruskal-Wallis tests in Table 10.3. In the preferred specifications of 'Levels 5' variants (and to

some extent 'Levels 4') p-values indicate rejection of equal subperiod medians in most cases. 'Levels 3' specification accepts equality, but this specification performed less reliably in the Monte Carlo exercise.

All models seem to agree that fundamentals had high explanatory power in the cross-section of spreads before the financial crisis.³ The log spreads specifications show a decline in the fundamental variance share in the financial crisis and even more in the sovereign crisis, before a gradual ascent in the explained share of the variation at the end of the sample. These results allow the following statement.

Thesis 2. (*Fundamental variance explained*) *The hypothesis that the variance share attributable to country fundamentals in the cross-sectional variance of log sovereign credit spreads is stable in time is rejected.*

10.1.3 Robustness checks and partial explanations for results

These results are descriptive in nature and do not yet address reasons for these findings. As argued throughout the thesis, there are various possibilities for observing time-variation in estimated fundamental effects in credit risk pricing.

These are summarized here:

1. **True repricing of risk (spreads).** Spread sensitivity to domestic fundamentals changes in the cross-section when spreads of sovereigns with weaker vs stronger fundamentals are unequally affected by non-fundamental or non-domestic factors. By design then, the slope of the linear fit of spreads to fundamentals will change. As shown in Chapter 8 ratings are linked close to exponentially to spreads and via a logistic function to default probability. Therefore any global factor (whether fundamentals-rooted or not) that affects credit risk (the log odds of default, $\log \lambda / (1 - \lambda)$) evenly across the rating spectrum, will qualify as a factor that changes the spread-to-ratings slope: changes in global liquidity conditions, global real interest rates and global prospects for trend growth. A deterioration in these factors increases spreads of worse-rated issuers proportionately more and therefore spread sensitivity to ratings in the cross-section will increase.⁴ However, due to the mentioned close to multiplicative nature of these global effects on credit spreads, the logarithmic transformation of spreads can separate these external effects into an additive term, which would then leave the slope of fundamentals to log spreads unaffected.

³Note the difference compared to sensitivity of spreads to fundamentals, which in contrast declined before the onset of the crisis).

⁴Of course, shocks may also unevenly affect log odds of default across the rating spectrum. What makes the case of even shocks interesting, however, is that log (or, elsewhere, CRRA) utility and linear effects on log utility are standard modelling choices (also followed in the theoretical models of the thesis) and this is shown in Chapter 8 to linearly impact the log odds of default (see equations 8.1-8.5). Therefore changes in global variables (such as global shocks to trend growth) that affect log utility linearly, lead to equal changes in log odds of default across the rating spectrum.

2. **True repricing of risk (log spreads).** There could be factors that influence the sensitivity of log spreads to domestic fundamentals. By the same token as above, this depends on whether these factors have an effect on log spreads that are heterogenous across the rating spectrum. For instance, several types of external shocks or risk premia could impact the pricing of domestic risks in developed and emerging markets, or various regions of the world differently. If the risk premia could be better hedged on emerging market bonds as opposed to developed markets or if US quantitative easing or the eurozone crisis had an effect on risk pricing in developed markets much more than emerging markets, then these could change spreads of better-rated developed markets vs worse-rated emerging markets, influencing the log spread sensitivity to ratings in the full cross-section.⁵
3. Finally, there are three important **cases of misspecification**, when the true sensitivity of spreads to fundamentals does not change through time, but the estimated sensitivity does.
 - (a) Measurement noise: when the proxy for fundamentals is noisy, attenuation bias leads to the estimated effect being smaller in absolute value. When the amount of noise changes in time, this may appear to change the sensitivity of spreads to fundamentals.
 - (b) Omission. Some aspects of country fundamentals may not be possible to measure at all. If these aspects are correlated with both spreads and the included proxies, then included proxies could still pick up this effect (and show a biased coefficient of their own partial effects). However, if these omitted aspects have a time-varying correlation with included proxies in the cross-section, then this could lead to a false estimate of time-variation in fundamental effects.
 - (c) Functional form misspecification. Related to the above (1) and (2) points, it is clear that simply the wrong choice of the functional link between spreads and fundamentals can lead to automatic shifts in estimated coefficients even if the true effect is stable. However this form of misspecification can only be assessed when the true data generating model is known.⁶

From the viewpoint of robustness checking Thesis 1a, 1b and 2, it is useful to try various alternative specifications that may lead to more robust results in terms of fundamental effects. If time-variation of effects is reduced due to a variation of the model, then that both serves as an

⁵Note that if there were different effects on domestic fundamentals across ratings, this would by itself not affect sensitivity to spreads. If ratings were a good proxy, the slope of log spreads-to-ratings would remain unchanged, because if default risk increased ratings and spreads would both increase simultaneously.

⁶The thesis does argue that the logarithmic spread form is more appropriate to use in estimations compared with the linear specifications, because it leads to more robust estimates in both time and cross-section. Because of its more robust property, this specification also serves as a more conservative test regarding the null hypothesis of time-invariance. However the thesis does not suggest that the true model is the one with logarithmic spreads as this would conceptually require knowing the exact pricing functions that market participants use. It is more plausible to think that participants use a variety of models and these happen to aggregate into a functional form that is empirically better characterized by log spreads versus ratings than spreads versus ratings.

explanation for the initial finding of time-variation and as a robustness check of the finding of time-variation. If these alternative specifications still reject time-invariance, then that supplies added support to Thesis 1a, 1b and 2.

The role of functional form

Relating to points (1), (2) and (3c) of the above list, the functional form estimated between the dependent and fundamentals may significantly affect the assessment of time-varying effects. It is natural to be interested in how much credit spreads (measured in basis points) are affected by fundamentals, however, it seems that (linearized) ratings are more robustly linked to log credit spreads instead. A unit increment in ratings has an approximately stable increment in the percentage change of spreads, but it has an increment that is increasing in spreads. Therefore an estimated specification with linear spreads automatically introduces time-variation (and cross-section heterogeneity) in estimated coefficients. While this time-variation is 'real' and it is interesting from a policy viewpoint, it is more interesting from the viewpoint of modeling time-variation to look at the logarithmic spreads specification, because this may still be time-invariant (and allow cross-section homogeneity).

Figure 10.3: Cross-correlation and volatility related to ratings

Sources: author's compilation.

Notes: The figure reports scatter plots of (Y-AXIS:) mean correlation coefficients with other countries (upper panel) and mean of daily volatilities (lower panel) for CDS spread (left), log CDS spread (mid) and log CDS spread time series with a 20 basis point adjustment (right) and (X-AXIS:) linearized ratings (AAA: 1, AA+: 2, ...) for each country in the cross-section. Correlations are computed between the (log) spread time series of each country with respect to the time series of cross-section means of other country (log) spreads. Greek CDS spread volatility (basis points) is not included in the bottom left plot due to orders of magnitude difference compared to other volatilities.

All this sidesteps the question of why it is percentage changes in spreads that are stable in ratings rather than basis point changes. A plausible answer based on finance theory and empirical regularities described in Chapter 8, is that the volatility of log spreads and their correlation with systemic risk (e.g the EMBI Global composite) is closer to being homogenous across ratings than the volatility and correlations of spreads measured in basis points. This warrants increasing risk premia on ratings for basis point spreads, because investors holding bonds with worse ratings need to be compensated by higher premia for the larger covariance with the market. For bond investors, keeping higher volatility risky bonds on trading books has a larger cost in terms of capital cost than lower volatility high-grade bonds. For CDS derivatives positions higher margins are needed for positions where the underlying is more volatile. In general the higher expected loss

Indeed, Figure 10.3 left plots tell us that both spread correlations with the market and especially volatility is significantly increasing in ratings. In contrast, regarding log spreads (middle plots) higher ratings would actually command some risk discount, because in percentage terms better-rated issuers (lower ratings, on our scale) have higher volatility. A short calculation yields that a slight adjustment of spreads (adding 20 basis points to both CDS and bond spreads) results in the logarithmic transformation having a stable volatility in the rating spectrum. Correlations and volatilities after this adjustment are displayed in the right column of plots in Figure 10.3.

Table 10.4: Correlation of time-varying estimates and global variables

	CDS (basis points)			log CDS			log CDS w/adjustment		
	$\hat{\beta}_t$	$\hat{\gamma}_t$	VS(t)	$\hat{\beta}_t$	$\hat{\gamma}_t$	VS(t)	$\hat{\beta}_t$	$\hat{\gamma}_t$	VS(t)
PANEL A: Correlation of parameter estimates and variance share									
$\hat{\beta}_t$	1.000	-0.943	-0.728	1.000	-0.700	0.480	1.000	-0.475	0.576
$\hat{\gamma}_t$	-0.943	1.000	0.727	-0.700	1.000	-0.153	-0.475	1.000	-0.355
VS(t)	-0.728	0.727	1.000	0.480	-0.153	1.000	0.576	-0.355	1.000
PANEL B: Correlation of estimated parameters with global financial variables									
EMBIG	0.630	-0.351	-0.366	-0.305	0.856	0.117	-0.017	0.845	-0.077
US HY	0.607	-0.339	-0.304	-0.385	0.823	0.122	-0.110	0.804	-0.106
VIX	0.274	-0.078	-0.213	-0.184	0.582	0.226	-0.008	0.587	0.142
UST 10Y	-0.593	0.416	0.388	0.176	-0.591	-0.097	-0.027	-0.590	-0.025

Sources: author calculations.

Notes: The upper panel of the table reports correlations between changes of estimated time-varying model parameters ($\hat{\beta}_t$: RATING coefficient, $\hat{\gamma}_t$: period effects) and the variance share attributed by the model to RATINGS (VS(t)). The bottom panel reports correlations between the changes of these model estimates and changes in global financial variables, the JPM EMBI Global index, the US BBB-AAA High Yield index, the VIX index, and the 10-year US Treasury yield.

The upper panel of Table 10.4 reports correlations of quarterly changes of model parameter estimates of the rating coefficient, $\hat{\beta}_t$, the time-varying intercept, $\hat{\gamma}_t$ and the variance share attributed to fundamentals. The bottom panel reports the correlation of these estimates with quarterly changes of global financial indicators.

The correlation of global shocks and the rating sensitivity of (linear) spreads (CDS basis points) is consistent with the volatility patterns seen in Figure 10.3. When systemic risk increases (the EMBIG, VIX, BBB-AAA high yield indices increase and, apparently, US Treasury yields decrease), then the sensitivity of CDS spreads to ratings significantly increases, hence correlation of $\hat{\beta}_t$ and EMBI Global, the VIX index, US High Yield spreads are positive. This con-

firms that global shocks 'automatically' result in changing fundamental effects (a larger spread sensitivity to ratings) in such a model setting.

In contrast, in the logarithmic CDS specifications it is rather the intercept, $\hat{\gamma}_t$, that changes due to global shocks. In periods when risk indicators, such as the EMBIG, the US high-yield spreads or the VIX increase, $\hat{\gamma}_t$ also tends to significantly increase, therefore log CDS spreads tend to generally increase (whereas $\hat{\beta}_t$ decreases somewhat). Hence this reaction is very much different as in case of linear spreads: as global risk shocks lead to a general increase of the cross section of log spreads, rather than a differentiated increase of CDS (basis point spreads) resulting in much larger increases of spreads for worse rated issuers.

The logarithmic specification with adjustment achieves close to zero correlation with $\hat{\beta}_t$, whereas without adjustment, the slope declines slightly when risk increases, again consistent with volatilities decreasing in ratings.

A note is in place regarding US Treasury yields. As identified in Chapter 4, empirical literature estimates of the effects of US monetary policy have been particularly troublesome with less studies reporting the positive coefficient predicted by theory as its opposite (see Figure 4.1). Uribe and Yue (2006) propose that there is a time lag of US interest rate effects. Based on correlations in the above table, I would instead argue that it is the safe asset feature of US yields, which results in the counterintuitive negative coefficient estimates in spread regressions. US yields tend to decline when global risk increases (whether due to revised estimates of the future path of US monetary policy or a flight to liquidity/quality) confusing the true positive effect of pure monetary policy shocks on spreads. Of course one could argue that including other proxies of global risk should already control this counterintuitive effect, but it may be that these proxies are imperfect, leaving behind more of the negative correlation than what may be compensated by pure monetary policy shocks.

Regarding fundamental variance share, global risk premium shocks that increase nominal CDS spreads lead to a diminished variance share attributed to ratings in the linear, basis points specification. This plausibly occurs because as the curvature of the rating-spread relationship increases the linear fit becomes a worse tool to approximate spreads. In the logarithmic specifications the variance share does not have a mentionable correlation with global shocks.

Role of regionality

Relating to points (2) and (3b) above, some of the variation in the sensitivity of log spreads to fundamentals could be due to assets being priced differently across developed and emerging markets. Although there is substantial co-movement in financial assets globally, there is a strong case to make that regional shocks matter over and above global shocks and that there is only a mild correlation across common factors of different asset classes (for instance Kocsis, 2014). The reasons could be related to different investor groups and thus different liquidity shocks influencing different market segments, the role of regulation differences and institutions in general (e.g. short naked CDS bans, but also various macro- or microprudential regulations

that influence the cost and benefit of hedging) or just different exposures to significant shocks, such as the eurozone periphery crisis causing prices to change more in the eurozone and the developed world than in emerging markets worldwide.

Figure 10.4: Alternative specifications: ratings β and variance share

Sources: author's compilation.

Notes: The figure shows estimated rating coefficient time series (left plot) and time series of the variance share attributed to fundamentals (ratings and the growth rate) in alternative specifications. 'Lev5' is the original rating + real GDP growth specification. 'DEV', 'EZ', 'RLOW' add rating and developed country/eurozone/low-rating dummy interactions (different rating sensitivities are calculated for DEV, EZ member and non-member country groups based on these models). 'RATI' uses a measure of implied-ratings (predictions based on calculable persistence in rating trends as described in Chapter 8). 'RFUT' uses ratings with a 4-quarter lead.

Therefore it makes sense to investigate whether adding more flexibility to the model by allowing emerging/developed country or eurozone/non-eurozone country spreads to react differently could explain some of the seen time-variation.

The left plot in Figure 10.4 displays rating coefficients estimated in models that allow heterogeneity of ratings in developed/emerging countries ('DEV'/'non-DEV') or based on eurozone membership ('EZ'/'non-EZ'). Non-developed and non-eurozone countries have roughly the same path of β_t estimates as in the baseline ('Lev5') model with values fluctuating between 0.15 and 0.25. The developed country and eurozone rating coefficients are more volatile, starting below 0.1 before the onset of the crisis and rising to a peak of 0.3 around mid-2010 where sensitivity stays for a year before dropping lower back towards emerging market levels.

Based on this it seems that ratings appear to have been somewhat differently priced in the developed vs emerging world having had a much lower role in log spreads of the former group before the crisis. Then, an overshooting during the crisis is apparent as the market priced in credit risk for eurozone countries and ratings were lagged to follow. Eventually the sensitivity of spreads to ratings in the developed world levelled off as rating agencies also adjusted ratings toward the market assessment and the two groups appear to have had similar pricing of risk at the end of the sample.

Note that this pricing sensitivity of the 0.2 range is still considerably below the slope of the

rating implied default probabilities (around 0.5) as discussed in Chapter 8 (see Figure 8.12 right plot).

The right plot in Figure 10.4 shows that some of the variance share decline during the sovereign crisis can be explained by heterogeneity in rating effects across issuers. The models that separately estimate eurozone/developed country rating coefficients displayed a somewhat smaller decrease in the variance share attributed to fundamentals during the sovereign debt crisis. Of the two models, the one that separates countries by eurozone membership appears to better fit spreads.

Table 10.5: Robustness checks

	Specifications					
	Lev5	DEV	EZ	RLOW	RATI	RFUT
PANEL A: F-tests						
F-statistic	8.781	8.792	9.807	7.431	10.156	10.974
ν_1	94	141	141	141	47	47
ν_2	3230	3230	3230	3230	3522	3522
p-value	0.000	0.000	0.000	0.000	0.000	0.000
PANEL B: Subperiod means of $\hat{\beta}_t$ and Kruskal-Wallis p-values						
Pre-crisis (1)	0.243	0.230	0.230	0.238	0.272	0.238
Financial crisis (2)	0.179	0.176	0.174	0.169	0.211	0.185
Sovereign crisis (3)	0.152	0.148	0.146	0.157	0.171	0.150
Post-crisis (4)	0.182	0.184	0.184	0.178	0.209	0.183
KW 1-4	0.000	0.000	0.000	0.000	0.000	0.000
MW 1-2 vs 3-4	0.000	0.000	0.001	0.007	0.000	0.000
KW 1-4 vs 2-3	0.000	0.000	0.000	0.000	0.000	0.000
KW 1-3-4 vs 2	0.721	0.490	0.432	0.182	0.830	0.775
KW 1-2-4 vs 3	0.000	0.000	0.000	0.000	0.000	0.000
KW 2-3 vs 4	0.849	0.405	0.317	0.366	0.812	0.793
KW 3 vs 4	0.000	0.000	0.000	0.000	0.000	0.000
PANEL C: Subperiod means of the fund.variance share and Kruskal-Wallis p-values						
Pre-crisis (1)	0.910	0.924	0.924	0.919	0.881	0.879
Financial crisis (2)	0.840	0.848	0.850	0.846	0.841	0.844
Sovereign crisis (3)	0.748	0.789	0.809	0.759	0.724	0.750
Post-crisis (4)	0.845	0.853	0.852	0.855	0.856	0.862
KW 1-4	0.000	0.000	0.000	0.000	0.000	0.000
MW 1-2 vs 3-4	0.000	0.000	0.000	0.000	0.002	0.003
KW 1-4 vs 2-3	0.000	0.000	0.000	0.000	0.000	0.000
KW 1-3-4 vs 2	1.000	0.739	0.686	0.886	0.943	0.739
KW 1-2-4 vs 3	0.000	0.000	0.000	0.000	0.000	0.000
KW 2-3 vs 4	1.000	0.886	0.651	0.981	0.216	0.160
KW 3 vs 4	0.000	0.000	0.000	0.000	0.000	0.000

Sources: author calculations.

Notes: The table reports robustness checks of results published in Tables 10.1-10.3. See notes regarding F-tests, periods and Kruskal-Wallis tests therein. Specifications in the table have log spreads as the dependent. 'Lev5' is the original rating + real GDP growth specification. 'DEV', 'EZ', 'RLOW' add rating and developed country/eurozone/low-rating dummy interactions. 'RATI' uses a measure of implied-ratings (predictions based on calculable persistence in rating trends as described in Chapter 8). 'RFUT' uses ratings with a 4-quarter lead.

Table 10.5 attests that this added flexibility still does not result in a time-invariant model. F-tests still reject coefficient stability and so do Kruskal-Wallis tests that study cross-period variation. The results are essentially the same, confirming Thesis 1b and 2.

Other possible omissions and measurement noise

As argued upfront ratings do take into account most aspects of default risk, but they do not capture credit risk changes due to business cycle fluctuations and ratings are known to be lagged measures of credit risk with persistent trends. It is natural to test then whether these characteristics explain some of the observed time variation.

Including real GDP growth into the model already takes into account business cycle fluctuations and based on all tests and estimates this has a minimal influence on estimated rating effects. GDP growth measures could be argued to be a noisy proxy of what the market would really price (an expectation of the real business cycle in the future with premia on negative tail risk scenarios). Even if perfect proxies existed it would arguably show more acute growth concerns in the global financial crisis rather than the sovereign crisis, whereas the variance share dropped during the latter not the former period. This makes it unlikely that better measurement of growth would change results.

I conduct two tests regarding the lag and persistence of ratings to assess whether changes in these characteristics could have led to an observed drop in the variance share attributed to fundamentals. There is reason to think this factor could have been important, because ratings have significantly readjusted in developed countries in the 2009-2011 period (see Figure 8.1). Perhaps the market was quicker to respond and until ratings adjusted the estimated variance share declined.

On one hand instead of observed ratings, I use a predicted rating measure as described in Chapter 8 that is constructed via a regression that includes past ratings (levels and changes) as explanatory variables. On the other hand, I simply use the 4-quarter lead of ratings. Neither of the two measures can account for the drop in the variance share in the sovereign crisis (Figure 10.4). F-tests and Kruskal-Wallis test outcomes are also left unchanged. I also used time-varying rating implied default probabilities, which produces similar variance share path and magnitudes (not shown in the figure).

Summing up: the reasons for spread-ratings sensitivity changes

Overall, it seems that there are multiple reasons for the finding that spread sensitivity to ratings changes over time.

One reason, that is especially relevant in the fluctuation of coefficients in case of nominal, basis point spreads is that bond spreads and CDS spreads of differently rated issuers have a varied sensitivity to global shocks. Risky sovereigns book larger spread increases when global risk aversion increases, which raises spread sensitivity to ratings in the cross section.

The logarithmic transformation of spreads successfully mitigates much of this heterogeneity, because in percentage terms, spreads react much more similarly to global risk shocks. Log spread sensitivity to ratings therefore changes to a lesser extent and global risk aversion leads to close to uniform shifts in the full cross-section of log spreads. However, the log specification

is also not perfect in eliminating risk shocks as usually low-risk issuers tended to experience a somewhat larger effect on their spreads in percentage terms.

This was not always the case. In the market pricing of credit risk before the financial crisis, the market has discounted the sovereign risk in credit ratings increasingly more even in log spreads. Also in the financial crisis there was a substantially repricing of credit risk raising the slope even in log spreads at the height of the crisis. Search for yield in the former period and funding liquidity shocks in the latter period were widely cited developments in these times, which could have had an impact on log spread rating sensitivity.

Another factor, especially evident in the sovereign crisis, seems to have come from rating agency lagged reactions compared to the market in marking down the credit quality of risky developed country issuers. The financial crisis triggered a large fiscal reaction in developed countries due to which the market has increased spreads in this segment, which has led to a drop of the sensitivity of log spreads to ratings in general. Until the second part of the sovereign crisis period, such deviation between market and rating agency perceptions of credit risk also substantially lowered the variance share of the cross-section of log spreads that ratings could explain. As rating agencies eventually caught up with the market, the sensitivity of log spreads to ratings (and the variance share explained by ratings) has increased back.

10.2 Time-variation in the effect of the debt ratio

The last part of the thesis turns to the pricing of the debt ratio within spreads. The sensitivity of spreads to the debt ratio is, of course, of prime importance for policy-making as it is central to choosing optimal issuance. Large sensitivity of spreads to the debt ratio lower the value of running up debt. Moreover, politically, the debt ratio is only feasible to reduce at a slow pace, therefore any future variation in the sensitivity of spreads to the debt ratio is important, because debt will be rolled over at prevailing future prices. Although the theoretical literature is unanimous in its expectation of a positive effect of debt on spreads (Chapter 2), estimated coefficients in empirical studies reviewed in Chapter 4 have often found the effect insignificant and even negative in a few studies (Figure 4.1).

The debt ratio is of special importance for the current analysis, because the theoretical models proposed in Chapters 5, 6 and C.2 derive multiple factors due to which the sensitivity of sovereign credit risk and hence sovereign spreads to the debt ratio could change over time (and across issuers).⁷ Proposition 5.7 proves within Model I that even the sign of the effect is am-

⁷To recap, the theoretical model developed in Chapter 5 separates the effects of debt based on whether it is externally or domestically held. Domestic debt is argued to have a positive effect on the willingness to repay, lowering credit risk, because of the expected adverse consequence a default could exert on the domestic financial sector and, through that, on economic growth. External debt could either have a positive or a negative effect, which is determined by whether trend growth or the real interest rate paid on debt is larger, and the size of the effect depends on both the difference between these two variables, the size of the debt ratio and the expected haircut in case of default. Funding liquidity also influences how the debt ratio affects spreads. When liquidity evaporates, willingness to repay declines leading to a positive effect of debt on spreads. The model shown in Appendix C.2 studies funding liquidity, the ability to pay and uncertainty in more detail. It shows that IMF conditionality that

biguous. Moreover Chapter 5 shows that using a plausible parametrization of the model based on emerging market and developed country data, the sign of the effect of the debt ratio on SDV, the value of defaulting from a willingness to pay aspect, is *negative*! Based on the models in the theoretical chapters, positive coefficients on the debt ratio in spreads could be due to high real interest rates vs trend growth or liquidity factors and the ability to repay aspect that is largely ignored by mainstream sovereign debt theory. This makes the topic interesting from an academic point of view as well.

Figure 10.5: Time-varying debt ratio coefficient estimates and fundamental variance shares

Sources: author's compilation.

Notes: The figure shows the estimated time-varying coefficients of the debt ratio in 'Levels 5' panel regression with the log spread as the dependent variable (top left plot), the spread as dependent (bottom left), the log spread and the 'Levels 4' specification (top right) and the fundamental variance shares (bottom right). Regarding regressors included 'DEBT0' only has the debt ratio included and a constant. 'EMP 1' and 'EMP 2' include macroeconomic and political-institutional variables that have been commonly used in the empirical literature. 'RAT + EMP2' also adds ratings (See notes in Table 10.1 about these specifications.)

Figure 10.5 displays debt ratio coefficient estimates in four model settings (DEBT0: only has the debt ratio in the regression; EMP 1 and EMP 2 includes several macroeconomic fundamentals and 'RAT + EMP 2' includes macroeconomic variables and ratings) using the 'Levels 5' and 'Levels 4' estimation techniques. The top plots display coefficients in log spread regressions, the bottom left plot displays coefficients in the linear spread model.

The general tendencies of the debt ratio coefficient are similar under various model settings. The effect of the debt ratio on sovereign credit spreads was relatively high and positive in the early 2000's gradually declining up to and including the financial crisis at which time it also switched sign, briefly going into negative territory. In 2009 the trend in the time series reversed and the debt ratio became a more and more important factor that acted to increase sovereign

becomes more stringent with higher debt ratios leads to a larger perceived probability regarding liquidity-defaults and hence increases spreads.

credit spreads, reaching the peak at the height of the eurozone sovereign debt crisis in mid-2012. The debt ratio coefficient has declined since, but the magnitude of this decline is mixed across models.

There is a notable difference between the log spread and linear spread specifications in the dynamics of debt ratio pricing (Figure 10.5 top left vs bottom left plots). In the linear case the coefficient swings quickly between negligible to extreme in the crisis, whereas in the log specification dynamics are smoother. This is likely to be the influence of some extreme spreads (e.g Greece) that are several standard deviations away from most of the sample. In logarithmic terms, spreads of these countries are closer to others in standard deviation terms.

Lack of robustness of the linear specification is also revealed by the significant differences in spread sensitivity to the debt ratio when real GDP growth is added to the model. In contrast, sensitivity of log spreads to debt ratio are robust to inclusion of this variable.

That said, the debt ratio by itself only explained a minor, roughly 10 percent, share of the cross-country variance of log spreads even at the height of the sovereign crisis (bottom right plot in Figure 10.5). As showed before, ratings explained around 60-90 percent of the cross-sectional variation, so other fundamentals played a much more important role most of the time in the pricing of spreads. However, in the sovereign crisis the role of the debt ratio increased at the same time that the role of other fundamentals proxied by ratings weakened.

F-tests reported in Table 10.6 confirm that changes in the debt ratio coefficient over time have been statistically significant, rejecting the null of time-homogeneity for both the log spreads (Panel A) and linear spreads specifications (Panel B).

Table 10.6: Debt coefficient time-variance (F-tests)

	Specifications					
	DEBT0	RAT	RATDEV	EMP 1	EMP 2	EMPRAT
PANEL A: Log Spreads, EZ interactions						
F-statistic	1.548	5.731	2.651	2.551	2.773	2.708
ν_1	47	47	47	47	47	47
ν_2	3218	2928	2928	2889	2897	2897
p-value	0.010	0.000	0.000	0.000	0.000	0.000
PANEL B: Spreads, EZ interactions						
F-statistic	5.295	2.484	1.505	3.773	4.322	1.774
ν_1	47	47	47	47	47	47
ν_2	3218	2928	2928	2889	2897	2897
p-value	0.000	0.000	0.015	0.000	0.000	0.001
PANEL C: Log Spreads, Theory-based interactions						
F-statistic	4.404	3.459	2.195	2.639	2.210	1.633
ν_1	141	141	141	141	141	141
ν_2	2669	2650	2650	2627	2635	2635
p-value	0.000	0.000	0.000	0.000	0.000	0.000

Sources: author calculations.

Notes: The table reports robustness checks of results published in Tables 10.1-10.3. See notes regarding F-tests, periods and Kruskal-Wallis tests therein. Specifications in the table have log spreads as the dependent. 'DEBT0' only includes the debt ratio as regressor; RAT additionally has ratings and real GDP growth; RATDEV adds rating interacted with a developed country dummy; EMP1, EMP2: includes macroeconomic variables commonly used as in the empirical literature (see Table 10.1); EMPRAT: EMP2 specification and ratings as controls.

Moreover changes of the debt ratio coefficients were not only statistically significant, but they were of an economically important magnitude. Abstracting from all other factors, a country with a 60 percent debt-to-GDP ratio had its spreads raised by 30-80 percent, so a spread of 300 basis points would have jumped to 400-550 basis points range between 2008 and 2012 just due to a repricing of risk.⁸ Of course, repricing of other fundamentals could have acted the other way. However, for countries such as Hungary, where the high government debt stock was a key fundamental weakness with other fundamentals relatively sound, the sovereign crisis brought on a substantial repricing of sovereign debt not only in absolute but also in relative value compared to other sovereigns.

10.2.1 Is there evidence of wake-up call effects?

As discussed at the end of Chapter 4, several studies in the empirical sovereign risk literature – nearly all that have considered time-variation of this fundamental – have come to the same conclusion about the time-variation of debt pricing by identifying its increased role in the sovereign crisis (see Table 4.4). This unanimity is notable, because papers were varied in their choice of model specifications (log or linear spreads, levels or first/quasi-differenced series) and the sample used.

The studies that aimed to explain these findings usually referred to the wake-up call hypothesis (e.g. [Beirne and Fratzscher, 2013](#); [Giordano, Pericoli and Tommasino, 2013](#)) a theory attributed to [Goldstein \(1998\)](#) that investors, when experiencing a crisis, reprice assets based on the characteristics of the crisis country. This may have its roots in imperfect information ([Ahnert and Bertsch, 2015](#)) or behavioral biases as investors overreact to crisis shocks.

To assess the validity of the wake-up call effect, I would argue that it is important to base the analysis on a sample that is related less directly to the epicenter of the crisis. When one estimates split sample regressions with crisis countries (i.e. ones that experienced large spread increases) constituting a significant share of the cross-section sample, then by the design of least squares fitting the relatively bad fundamentals of the crisis countries will tend to be found significant in influencing spreads. This, however, may only tell us which fundamentals differentiate crisis countries from non-crisis countries rather than whether investors had really repriced these fundamentals. A better test of wake-up calls is to look at a different (non-crisis) country segment altogether. If the bad fundamentals of crisis countries receive higher spreads also in this sample, then the wake-up call argument is better supported.

Table 10.7 reports regression results with subperiod dummy variables to estimate time-variation in debt ratio pricing. The baseline subperiod is chosen to be the financial crisis (period

⁸To see this, consider an 0.005-0.01 increase of the debt ratio coefficient in log spreads. In Figure 10.5 top plots we see a 0.01-0.015 increase, but in non-eurozone countries this was smaller, around 0.005. (See Figure 10.6 top left plot and Table 10.7. Note that coefficients are multiplied by 100 in Table 10.7.) Since the debt ratio is given in percentage points, the change in the coefficient amounts to a 0.3-0.6 unit increase in (natural) log spreads, which translates into a 35-82 percent increase in nominal spreads.

Table 10.7: Debt ratio effects on EM/DEV credit risk (Regression results)

Regr. spec	(A) debt only		(B) w/ratings		(C) w/macro		(D) RAT depend		(E) w/CXeff	
Dependent	Log SPR		Log SPR		Log SPR		RATING		Log SPR	
	coef.	s.e.	coef.	s.e.	coef.	s.e.	coef.	s.e.	coef.	s.e.
<i>Regressors (debt)</i>										
debt	0.862***	(0.110)	-0.619***	(0.094)	0.116	(0.125)	5.633***	(0.391)	1.530***	(0.103)
debt_DEV	-2.065***	(0.108)	0.082	(0.103)	-1.072***	(0.110)	-6.966***	(0.316)	0.042	(0.183)
debt*p1	0.479***	(0.139)	0.886***	(0.137)	1.270***	(0.178)	0.133	(0.492)	0.006	(0.082)
debt*p3	0.482***	(0.157)	0.465***	(0.128)	0.454***	(0.147)	-0.639	(0.563)	0.477***	(0.079)
debt*p4	1.143***	(0.157)	0.735***	(0.126)	0.966***	(0.140)	0.796	(0.577)	0.999***	(0.085)
debt_DEV*p1	-0.552***	(0.141)	-0.587***	(0.134)	-1.001***	(0.143)	-0.406	(0.364)	-0.499***	(0.114)
debt_DEV*p3	1.129***	(0.144)	0.499***	(0.131)	1.024***	(0.127)	3.142***	(0.422)	0.605***	(0.104)
debt_DEV*p4	0.308**	(0.139)	-0.310**	(0.126)	0.342***	(0.121)	3.233***	(0.403)	-0.438***	(0.110)
<i>Regressors (other)</i>										
constant	-447.290***	(2.993)	-535.674***	(3.069)	-394.505***	(2.901)	786.135***	(11.986)	-522.528***	(5.877)
rating			17.882***	(0.369)						
RGDP yoy			-4.539***	(0.309)	-6.104***	(0.447)	-9.352***	(2.022)		
CA/GDP					1.032***	(0.172)	0.957	(0.979)		
RES/GDP					-0.032	(0.095)	0.144	(0.369)		
CorruptLow					-62.160***	(1.727)	-307.592***	(4.073)		
Pol Stab					0.670	(1.686)	-2.937	(6.630)		
FBAL/GDP					-1.504***	(0.376)	3.007*	(1.765)		
Period effects	Yes		Yes		Yes		Yes		Yes	
Cross-section effects	No		No		No		No		Yes	
R-squared	0.497		0.865		0.724		0.771		0.861	
Adj R-squared	0.482		0.860		0.714		0.765		0.854	
No. of cross-sections	55		52		51		51		55	
No. of pool observ	3620		3238		3094		2902		3693	

Sources: as described in Appendix A.1.

Notes: The table reports regression results with the log spread as the dependent variable except in specification (D) where credit ratings are the dependent. (For convenience log spreads are divided by 100 so that all coeff's are 100 times larger in the output. Otherwise several coeff's of interest would be of magnitude 0.01 and differences across specifications would be more difficult to see.) Explanatory variables include: the government debt ratio (debt) in percentage points (its coeff. means log spreads change by 0.01 for each percentage point increment in the debt ratio); the debt ratio interacted with developed country dummy variable; (p1,p3,p4) period-dummy interactions of the latter two variables; and other macroeconomic variables (RGDP yoy: year-on-year real GDP growth; CA/GDP: current account balance; RES/GDP: reserves/GDP; WGI Control of Corruption; WGI Political Stability; FBAL/GDP: fiscal balance) or ratings (three agency rating averages, linear scale) as controls. See Appendix Table A.8 for further information. Period dummies used relate to the 2000-2006 (p1), the 2010-2012 (p3) and the 2013-2016 (p4) time periods. Clustered standard errors are reported in parentheses. Asterisks denote usual significance levels at 1, 5 and 10 percent.

2) since the focus of interest is whether debt ratio pricing increased subsequently in the sovereign crisis period. I also look at a split of the sample along the developed/emerging country categories by including interactions with a developed country dummy variable (debt_DEV). With this regression setup the coefficient of interest is that of debt*p3, which assesses how much the effect of the debt ratio changed from the financial crisis to the sovereign crisis (period 3) within the emerging market group of countries. (The sum of coefficients of debt*p3 and debt_DEV*p3 shows how much the effect changed in developed countries.)

The results appear to confirm the wake-up call hypothesis relating to the pricing of debt within sovereign credit spreads in both emerging markets and developed countries. Debt ratio coefficient estimates have significantly increased in the sovereign debt crisis compared to the baseline financial crisis period according to all specifications. However, ratings did not seem to be recalibrated in the sovereign crisis period according to specification (D), where credit ratings are the regression dependent variables. Developed countries also experienced an additional repricing of debt in the sovereign crisis. Moreover, rating agencies also appear to have reacted by increasing the sensitivity of ratings to the debt ratio in this group of countries.

The magnitude of the effect change can be calculated as follows. Based on specification (A), the debt ratio coefficient changed by 0.479 in period 3 (from the period 2 value of 0.862). For a country with a debt ratio of 50 percent, this change has an effect of $0.479 \times 0.5 = 0.24$

on log spreads (debt variables are in percentage point of GDP, whereas coefficients in the table are multiplied by 100). For such a country, this translates into a 27 percent increase in spreads ($\exp(0.24) = 1.27$).

To compare this effect of coefficient change to the pure effect of a debt ratio change on spreads, note that a unit increase in the debt ratio would increase log spreads by 0.862 in period 2 and 1.341 in period 3. Therefore about 18 and 28 percentage point changes (in period 2 and period 3 respectively) would be needed to produce an equivalent effect. This shows that the effect of coefficient change is an economically substantial quantity.

The regression also provides suggestions on whether or not such effects lasted. Interestingly, in period 4 log spreads appear to have become even more sensitive to the debt ratio (the coefficient of debt^*p4 is larger than the one on debt^*p3). This contradicts other studies, which instead found such rising sensitivity of spreads to debt to have been temporary (Kocsis and Monostori, 2016; Audzeyeva and Fuertes, 2018). The finding here of longer-term increase pertains to emerging markets. In the developed countries segment, the debt ratio coefficient came down in the last subperiod in sovereign spread regressions (the coefficients of $\text{debt}^*p4 + \text{debt_DEV}^*p4$ is less than $\text{debt}^*p3 + \text{debt_DEV}^*p3$) in most specifications.

Rating agencies seem to have recalibrated emerging market ratings to better reflect debt ratio differences – in effect catching up with the market. This may at least in part explain why the variance share of ratings in spreads declined in the sovereign crisis and rose afterwards. Figure 10.6 (top right plot) shows that the fully flexible specifications with ratings and macro variables (RAT+EMP2) display a smaller decline in the sovereign crisis than the declines seen in previous models (see Figure 10.5 bottom right plot), where the debt ratio time-varying effect was missing.

Thesis 3. (*Debt ratio wake-up call*) *The hypothesis that the pricing effect of the debt ratio on logarithmic sovereign credit spreads increased in the sovereign crisis is accepted.*

There are two important weaknesses of this analysis. First, it does not allow changes to coefficients of other determinants of sovereign spreads. This may be problematic if these determinants are correlated with debt and changes in the estimated debt coefficients are in fact due to a change in the effects of these other, correlated variables, and it may invalidate Thesis 3.

Second, it may be that changes in the estimated effects of the debt ratio are in fact changes of a variable that has an effect on spreads via an interaction with debt. If spreads are generated by the interaction of a variable X and debt (Z) with a time-homogenous effect γ , then the estimated debt ratio effect $\hat{\beta}_t = \gamma X_{it}$ and changes in this effect may simply be a consequence of X changing globally. This would not invalidate the above statement, but it would provide explanations for it.

These issues are addressed next.

10.2.2 What may explain the increasing sensitivity of spreads to debt?

The top left plot of Figure 10.6 displays time-varying debt ratio effects on the logarithm of spreads in two 'Levels 5' specifications (one with debt variables only and one, 'EMP2', with several macrovariables) with the debt ratio and its interaction with a eurozone dummy variable. The plot clearly supports Thesis 3. The debt ratio coefficient increased significantly during the sovereign crisis in both emerging and developed countries with some of the increase reversed in the eurozone debt market after 2012.

In the bottom plots of Figure 10.6 I include four debt-related factors that the theoretical chapters propose. The first two relate to (government) external and foreign-currency debt to GDP (EXTERN, FXDEBT). The theoretical models propose that the effect of external debt depends on real interest rates vs trend growth (a willingness to pay aspect), whereas external and foreign currency debt relate to sovereign risk via funding liquidity conditions (an ability to pay aspect). When market funding deteriorates, there is an increased chance that a sovereign with high external, foreign-currency debt might be caught up in a funding crisis especially if there is a weak backstop from central bank last-resort-lending and relations with international official creditors are problematic (as was the perceived case in the eurozone). This perception could already lead to a self-fulfilling panic and increasing spreads as argued by [De Grauwe and Ji \(2013\)](#).

The third variable (DOMxPC) is domestic debt/GDP interaction with a financial development variable. This is to capture the commitment device of domestic debt in countries with a large financial sector. Based on the theoretical model, a large domestic financial sector holding public debt would supply additional motivation for the government to repay as a default could have adverse economic implications (as in [Acharya, Drechsler and Schnabl, 2014](#); [Gennaioli, Martin and Rossi, 2014](#)). While the former, willingness to pay, effect acts to reduce spreads, the latter, aspect acts to increase them via augmenting concerns about the ability to pay.

Finally, the debt ratio interaction with an institutional background proxy (WGI control of corruption, DEBTxINST) is also included in the model. When the debt ratio is high and market-friendly institutions are lacking, there is a greater chance of opportunistic behavior on the part of government and conflicts with official lenders regarding conditionality terms, which increases the chances of a default.

The bottom plots of Figure 10.6 suggests that the debt ratio increase seen in both developed and emerging markets was mostly related to a repricing of the risk that external government indebtedness means for investors. The increase in coefficients appear to have been somewhat reversed after 2012, but the effect still significantly exceeds that in the global financial crisis.

In contrast, foreign-currency debt seems to have played a larger role before the sovereign crisis and its coefficient has dropped significantly since. This development seems to be robust across several specifications (also several not presented here). Still, it could be argued that in the case of the eurozone, where much of the debt ratio repricing took place (as seen in the top

Figure 10.6: Time-varying debt ratio interaction effects

Sources: author's compilation.

Notes: The figure shows the estimated time-varying coefficients in 'Levels 5' panel regressions (top left, bottom plots) and the time-varying variance share of models (top right). DEBT0 specification only has the debt ratio included and a constant. The 'EMP 2' specification includes macroeconomic and political-institutional variables that have been commonly used in the empirical literature. 'EMP2+RAT' also adds ratings. (See notes in Table 10.1 about these specifications.) The top left plot has the debt ratio interacted with EZ dummies to trace separate effects inside and outside this block. Bottom plot models have interactions of the debt ratio with external share of debt (EXTERN), the FX share of debt (FXDEBT), domestic share and private credit to GDP (DOMxPC), and the negative of WGI control of corruption (INST). These plots only include the debt ratio in these interactions, it is not added separately.

left plot) the separation between domestic and foreign currency debt is not all evident. As there was speculation on redenomination risk, debt could have been increasingly thought of as foreign currency debt. Even without redenomination, it was not clear throughout the sovereign crisis how much the European Central Bank is willing to stand in as a lender of last resort, which is the key difference between domestic currency and foreign currency debt. If the central bank does not lend to government in emergency cases, then domestic (euro-)denominated debt are just as prone to self-fulfilling fears of funding crisis as argued by [De Grauwe and Ji \(2013\)](#). Moreover, since eurozone countries typically have a high debt share held externally, the bad proxy of foreign currency debt in case of the eurozone might have resulted in the increase of the external debt coefficient.

The changes in effects are less pronounced in case of the last two factors. The domestic debt and financial development interaction and the debt-institutions interaction has mixed signs

across specifications in the first place and the changes in the sovereign crisis period finds only weak support and are not robust across specifications and samples.

Table 10.8: Debt interaction effects on credit risk (Regression results)

Regr. spec	(A1) EXTdebt		(A2) FXdebt		(A3) both		(C1) EXTdebt		(C2) FXdebt	
Dependent	Log SPR		Log SPR		Log SPR		Log SPR		Log SPR	
	coef.	s.e.	coef.	s.e.	coef.	s.e.	coef.	s.e.	coef.	s.e.
Regressors (debt)										
EXTdebt	0.414*	(0.214)			0.151	(0.236)	-0.400*	(0.221)		
FXdebt			2.741***	(0.211)	1.793***	(0.204)			3.453***	(0.248)
debt_DEV	-0.936***	(0.080)	0.772***	(0.106)	-0.475***	(0.122)	-0.630***	(0.098)	0.458***	(0.091)
DOMdebt*FinDev	0.817***	(0.160)	-0.590***	(0.199)	0.465***	(0.228)	-0.708***	(0.160)	-1.153***	(0.156)
debt*Corrupt	0.882***	(0.078)	1.288***	(0.073)	0.907***	(0.075)	-0.069	(0.091)	0.475***	(0.072)
EXTdebt*p1	1.733***	(0.383)			1.480***	(0.397)	1.623***	(0.372)		
EXTdebt*p3	2.807***	(0.271)			2.679***	(0.259)	2.638***	(0.255)		
EXTdebt*p4	1.832***	(0.262)			1.808***	(0.258)	1.868***	(0.244)		
FXdebt*p1			-1.287***	(0.280)	-1.056***	(0.252)		(0.266)	-0.302	(0.339)
FXdebt*p3			-0.816***	(0.292)	-0.934***	(0.277)		(0.142)	-2.094***	(0.286)
FXdebt*p4			-0.199	(0.331)	0.109	(0.316)		(0.142)	-1.707***	(0.288)
DOMdebt*FinDev*p1	-0.565	(0.356)	-2.089***	(0.460)	-1.442***	(0.449)	-0.298	(0.266)	-1.070***	(0.364)
DOMdebt*FinDev*p3	1.381***	(0.180)	0.913***	(0.220)	1.401***	(0.223)	1.447***	(0.142)	0.751***	(0.172)
DOMdebt*FinDev*p4	1.715***	(0.196)	1.251***	(0.227)	1.709***	(0.235)	1.729***	(0.142)	1.040***	(0.171)
debt*Corrupt*p1	0.518***	(0.149)	-0.080	(0.112)	0.215	(0.160)	0.653***	(0.137)	-0.157*	(0.090)
debt*Corrupt*p3	-0.028	(0.085)	-0.448***	(0.076)	0.045	(0.084)	0.093	(0.090)	-0.396***	(0.065)
debt*Corrupt*p4	0.085	(0.085)	-0.282***	(0.076)	0.066	(0.083)	0.268***	(0.089)	-0.179***	(0.065)
Regressors (other)										
constant	-439.268***	(3.545)	-432.431***	(3.452)	-457.918***	(0.083)	-402.524***	(3.594)	-400.825***	(3.393)
rating										
RGDP yoy							-4.887***	(0.573)	-5.417***	(0.581)
CA/GDP							1.620***	(0.190)	1.536***	(0.226)
RES/GDP							0.522***	(0.137)	-0.003	(0.088)
CorruptLow							-58.251***	(2.312)	-57.296***	(2.910)
Pol Stab							-3.521**	(1.781)	-0.278	(2.194)
FBAL/GDP							-2.675***	(0.409)	-2.622***	(0.395)
Period effects	Yes		Yes		Yes		Yes		Yes	
Cross-section effects	No		No		No		No		No	
R-squared	0.587		0.595		0.652		0.699		0.754	
Adj R-squared	0.571		0.579		0.637		0.686		0.743	
No. of cross-sections	51.000		43.000		43.000		50.000		43.000	
No. of pool observ	2583.000		2185.000		2185.000		2458.000		2126.000	

Sources: as described in Appendix A.1.

Notes: The table reports regressions of debt-related proxies and other fundamental proxies on log spreads and ratings (D). 'EXTDebt' refers to external government debt/GDP, 'FXDebt' refers to foreign-currency debt/GDP, 'DOMdebt*FinDev' is the interaction of domestic government debt/GDP and IMF's financial development index. 'debt*Corrupt' is the interaction of the debt ratio and WGI control of corruption. The sources of these variables are listed in Appendix Table A.8.

Regressions reported in Table 10.8 estimate these relationships on the usual four subperiods (pre-crisis, financial crisis, sovereign crisis, post-crisis). Since external debt to GDP and foreign currency debt to GDP are correlated across samples they are separately included in four of the five specifications.

Similar to the time-varying estimates displayed on the figure above, external debt to GDP seems to be priced most during the sovereign crisis period (p3), with the pre-crisis (p1) and post-crisis (4) period also having significantly larger coefficients than the baseline financial crisis (p2).

Coefficients on foreign-currency debt to GDP displays a reverse pattern, being highest in the financial crisis and lower in the other three subperiods as coefficients on p1, p3, p4 are negative. On the whole though foreign currency debt does affect pricing positively throughout the sample, as it should according to theory, because the baseline (p2) coefficient is large positive offsetting the relative negative effects in different subsamples.

Again coefficients on domestic debt interacted with financial development have mixed signs across specification, and therefore do not support negative coefficients prescribed by theory. The

institutional proxy (control of corruption) also has weak and mixed effects across specifications.

In sum, the time-varying and subsamples estimates suggest that it was the coefficient on external debt/GDP, which has increased substantially during the sovereign crisis and which has thus contributed most to the increased pricing of the debt ratio in general. Based on the theoretical chapters in the thesis, this could be a result of real interest rates having increased relative to trend growth. However, the result should be taken with a pinch of salt as eurozone countries typically have low foreign currency debt and high external debt shares, so any fear of redenomination or lack of help from the ECB could have also contributed to the increased coefficient on external debt.

Conclusions

Country fundamentals and sovereign credit risk have a complex relationship. The theoretical literature has proposed a plethora of relevant fundamentals that investors in sovereign credit markets and credit rating agencies need to consider. However, the empirical literature has struggled to come up with robust models that can pin down the practical relevance of individual fundamental factors. The empirical literature review in the thesis shows that the significance and even the sign of effects in case of most country fundamentals were mixed across studies. Due to the lack of robust findings, it is also not clear whether the commonly found time-variance in fundamental effects could really be interpreted as the re-pricing of fundamentals within spreads or rather they derive from problems of the estimation method and the data.

The thesis introduces a stylized sovereign credit risk model that aims to broaden the list of fundamentals usually included in theoretical models. It specifically adds three features that have been discussed in the literature but are missing from models based on the framework of [Eaton and Gersovitz \(1981\)](#): (i) it separately handles external and domestic issuance, (ii) adds two political economy aspects, (iii) considers funding liquidity crises and liquidity defaults. The model shows that several fundamentals have effects on default risk that depend on values of other fundamentals. This can be one factor that leads to time-variation in estimated effects in reduced-form models.

An important case at hand is the debt ratio. In contrast to other models that uniformly predict credit risk to increase with debt, the model in the thesis shows that the sign of the debt ratio effect is ambiguous. In countries with domestic issuances held by a large financial sector the effect can be negative, because larger debt increases the risk of significant output losses that a default would cause. In case of external debt – assuming that debt ratios can change only gradually – the sign of the effect depends on the difference between trend growth and real interest rates, because this determines the direction of capital flows, which influences how rolling over debt impacts utility. The debt ratio effect can also become significantly positive, especially if the following hold simultaneously: the ratio of foreign currency, short-term bonds are large in the debt stock; there is a global liquidity shortage; central bank reserves are low or not available for use as a last resort; market institutions and the government political stance toward repaying is weak.

The empirical sections of the thesis deal with econometric and data issues that may lead to lack of robustness and potential spurious findings of time-varying fundamental effects.

I argue in the thesis that simple reduced-form models are more robust when the dependent variable is the logarithm of sovereign credit spreads and not a linear form of spreads. As I show, spreads are exponentially related to the log-odds of default. Empirical analysis shows that credit ratings and global shocks have effects on spreads that increase exponentially with the level of spreads. Linear regression estimates of fundamental effects on spreads will then be particularly sensitive to the sample. Estimated effects will rise in crisis, when credit spreads globally rise and they will be lower in normal times. Due to the multiplicative nature of effects that this functional form implies, estimates will also be more sensitive to omission of relevant

determinants. In contrast, log spreads are approximately linearly related to fundamentals and global factors, which leads to better properties of empirical models in this form. Since the empirical literature is roughly equally divided between using linear and logarithmic sovereign spread specifications, this result could be a useful contribution for this research community.

The empirical section carries out an extensive Monte Carlo study that evaluates which tests and specifications are best to use for identifying whether time-variation in effects was present. The Monte Carlo exercise is tailored to the current application mimicking basic properties of spreads and fundamental proxies. The results in general favor more parsimonious specifications (interestingly, omitted cross-section effects appear to lower errors in both coefficient stability tests and coefficient estimates) and to use the levels specification for spreads and fundamentals instead of quasi-differenced forms.

Hypothesis tests confirm time-varying fundamental effects. This result is robust to using various estimation methods, linear or log spread specifications, using ratings or explicit macroeconomic variables as fundamental proxies. In the log spreads specification, fundamental effects and the variance share of fundamentals both declined in much of the sample, reaching their lows in the sovereign crisis period. Some of the decline is related to heterogeneity in effects based on eurozone membership and is also a consequence of rating agencies moving slower to mark down the credit quality of developed countries relative to market participants.

The last part of the thesis turns to the wake-up call hypothesis ([Goldstein, 1998](#)) regarding the debt ratio in determining sovereign spreads. The results support the hypothesis: log spreads have become more sensitive to the debt ratio both in developed countries and in emerging markets. Interestingly, rating agencies - although with a significant lag compared to the market - appear to also have given larger weight to the debt ratio after the eurozone sovereign crisis. In fact, this lagged reaction of agencies and thus the disparity of how the market and rating agencies evaluated the effect of debt on spreads could partly explain the decline of rating explanatory power in spreads during the sovereign crisis. Relating to the theoretical models, the changes in debt effect appear to be channeled through the external debt component, which suggests perceptions of increased real interest rates relative to trend growth or a larger role of funding liquidity aspects in credit risk.

Changes in the debt ratio coefficients were not only statistically significant, but they were of an economically important magnitude. A country with a 60 percent debt-to-GDP ratio would have *ceteris paribus* had its spreads raised by 30-60 percent between 2008 and 2012 due to the repricing of this fundamental variable. Both policymakers and investors should take into account this type of model uncertainty in their decisions.

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Appendix

Appendix A: Data

There are several datasets that the thesis relies on in empirical applications. Much of the empirical part of the thesis is built on macro and financial data comprising 60 countries on the 1999-2016 sample on quarterly frequencies. For purposes of investigating properties of spreads and ratings a higher frequency (daily) data set is used. A historical data set that goes back to the 1970s for a large cross-section of (125) countries is annual frequency and this is used for calibrating theoretical model parameters and checking model predictions.

A.1 Basic data set

The basic data set used in the empirical parts of the thesis includes sovereign spreads, ratings, macroeconomic data for 60 countries¹ in the period 1999-2016.

A.1.1 Sovereign credit ratings

Credit rating changes of the three major ratings agencies (Moody's, Standard & Poors' and Fitch Ratings) were downloaded from Bloomberg for 107 countries in the period 1992-2017. These were used to assemble a database of daily ratings data on this sample. The ratings dataset includes granularity up to the modifiers of letter grades (e.g. AA+, AA, AA-). Only a subset (60 countries, Jan 1999 - Nov 2017) is used in the main empirical analysis in Chapter 10, though the full data set is used in Chapter 8 to analyze key properties of ratings and to create rating-implied default probabilities.

Table A.1 displays descriptive statistics of ratings in the analyzed time period. Basic statistics of the three agencies are similar. Regarding time subsamples, the pre-2007 sample had the least frequent rating changes and the sovereign crisis period had the most frequent changes (last column). The number of country-time observations with rating changes are still small compared to the number of days with stable ratings. An advantage of combining ratings (RATING avg)

¹The 60-country dataset contains: Argentina (CDS, EMBI), Australia (CDS), Austria (CDS, yield spread over Bund), Belgium (CDS, yield spread over Bund), Brazil (CDS, EMBI), Bulgaria (CDS, EMBI), Chile (CDS, EMBI), China (CDS, EMBI), Colombia (CDS, EMBI), Croatia (CDS), Czech Republic (CDS), Denmark (CDS), Egypt (CDS, EMBI), Estonia (CDS), Finland (CDS, yield spread over Bund), France (CDS, yield spread over Bund), Germany (CDS), Greece (CDS, yield spread over Bund), Hong Kong (CDS), Hungary (CDS, EMBI), Iceland (CDS), Indonesia (CDS, EMBI), Ireland (CDS, yield spread over Bund), Israel (CDS), Italy (CDS, yield spread over Bund), Japan (CDS), Kazakhstan (CDS, EMBI), South Korea (CDS), Latvia (CDS), Lebanon (CDS, EMBI), Lithuania (CDS), Malaysia (CDS, EMBI), Mexico (CDS, EMBI), Netherlands (CDS, yield spread over Bund), New Zealand (CDS), Norway (CDS), Pakistan (CDS, EMBI), Panama (CDS, EMBI), Peru (CDS, EMBI), Philippines (CDS, EMBI), Poland (CDS, EMBI), Portugal (CDS, yield spread over Bund), Romania (CDS, EMBI), Russia (CDS, EMBI), Slovakia (CDS), Slovenia (CDS), South Africa (CDS, EMBI), Spain (CDS, yield spread over Bund), Sri Lanka (EMBI), Sweden (CDS), Switzerland (CDS), Thailand (CDS), Tunisia (CDS, EMBI), Turkey (CDS, EMBI), UK (CDS), Ukraine (CDS, EMBI), Uruguay (EMBI), US (CDS), Venezuela (CDS, EMBI), Vietnam (CDS, EMBI)

is that this way the frequency of observed changes in ratings increases. This data set does not include the information of rating outlooks and rating watchlists.

Table A.1: Descriptive statistics of ratings data (pooled data)

	mean	median	stdev	NX	T	N	N_RCH	N/N_RCH
Moody's	7.9	8.0	5.1	102	9460	727106	221	3290.1
S&P	8.1	8.0	5.1	103	9460	749624	297	2524.0
Fitch	8.1	9.0	5.1	98	8508	601120	202	2975.8
RATING	8.4	9.0	5.1	107	9460	807006	738	1093.5
avg								
pre-2007	7.7	7.7	5.0	101	5479	392639	247	1589.6
2007-2009	8.5	9.0	5.1	103	1097	112449	103	1091.7
2010-2012	8.8	10.0	5.0	105	1097	114525	167	685.8
post-2012	9.2	9.7	5.1	106	1790	187701	221	849.3

Sources: Bloomberg

Notes: Descriptive statistics for pooled variables (unbalanced panel). Daily data frequency, 107 countries, time sample: 1992-2017. NX: number of cross-section units with valid data. N_RCH: number of country-time observations with ratings that changed from previous periods.

The literature posits that ratings have persistent dynamics and are characterized by weak mean reversion. These are confirmed on the data set used in the thesis. Out of several estimated specifications, the lowest BIC models are reported for monthly and quarterly data in Table A.2.

Table A.2: Time series regressions of ratings

Regr. spec	(A) long quarterly		(B) long monthly		(C) short quarterly		(D) short monthly	
Dependent	ΔRAT_t		ΔRAT_t		ΔRAT_t		ΔRAT_t	
Regressors	coef	se.	coef	se.	coef	se.	coef	se.
constant	0.028***	(0.008)	0.007***	(0.003)	0.028***	(0.008)	0.007***	(0.003)
RAT_{t-h}	-0.003***	(0.001)	-0.001***	(0.000)	-0.003***	(0.001)	-0.001***	(0.000)
$\Delta^h RAT_{t-h}$	0.178***	(0.013)	0.064***	(0.008)	0.282***	(0.017)	0.261***	(0.014)
$\Delta^h RAT_{t-2h}$	0.104***	(0.014)	0.075***	(0.008)	0.109***	(0.018)		
$\Delta^h RAT_{t-3h}$	0.022	(0.014)	0.057***	(0.008)				
$\Delta^h RAT_{t-4h}$	0.081***	(0.014)	0.068***	(0.008)				
$\Delta^h RAT_{t-5h}$	0.035**	(0.014)						
h	1		1		2		4	
R-sq.	0.071		0.022		0.066		0.022	
R-sq.adj	0.069		0.022		0.065		0.022	
BIC	2999.66		-10705.01		3035.9		-10731.43	
No. observations	5503		16943		5520		16943	

Sources: author calculations.

Notes: Linear regressions of rating changes on constant, lagged ratings (h-period lag) and lagged rating changes (multiple h period lags). Long specifications report the optimal rating change lag regressions (lowest BIC), which include subsequent lags. Short specifications report the optimal lags of regressions for larger than 1 steps (h>1) rating change lags.

The level of lagged ratings has a significant negative effect on rating changes, which indicates mean reversion. The changes of lagged ratings have significant positive effects suggesting that rating changes in the recent past tend to lead to rating changes of a similar direction, thus leading to trends in ratings.

A.1.2 Sovereign credit spreads

General descriptives

There are three types of sovereign credit spread data used in the thesis.

Table A.3: Descriptive statistics of sovereign spreads data (pooled data)

	mean	median	stdev	TS var.share	CX var.share	NX	T	N
BOND spreads (basis points)								
full sample	326.4	195.0	552.6	0.05	0.34	37	4912	168465
developed countries	102.7	18.0	307.9	0.20	0.20	10	4912	48118
emerging markets	415.8	255.0	601.3	0.09	0.31	27	4912	120347
pre-2007	351.3	173.0	722.4	0.04	0.50	35	2084	66402
2007-2009	284.8	180.0	367.6	0.23	0.50	37	784	28569
2010-2012	328.1	214.1	365.9	0.06	0.66	37	782	27800
post-2012	315.0	207.0	446.7	0.02	0.75	37	1262	45694
CDS spreads (basis points)								
full sample	253.8	127.3	619.6	0.03	0.35	54	2217	118423
developed countries	186.6	50.9	795.7	0.06	0.24	20	2217	43433
emerging markets	292.7	165.7	485.1	0.05	0.50	34	2217	74990
2007-2009	257.7	138.0	418.9	0.10	0.61	54	521	27045
2010-2012	276.0	141.7	782.6	0.02	0.42	54	782	42127
post-2012	232.6	109.9	549.5	0.01	0.62	54	914	49251
BONDS spreads (logarithm)								
full sample	5.0	5.3	1.5	0.1	0.63	37	4912	162547
developed countries	3.3	3.1	1.6	0.5	0.20	10	4912	42200
emerging markets	5.6	5.5	0.8	0.2	0.45	27	4912	120347
pre-2007	4.8	5.3	1.8	0.0	0.82	35	2084	61299
2007-2009	4.9	5.2	1.5	0.2	0.72	37	784	28135
2010-2012	5.4	5.4	1.0	0.1	0.77	37	782	27645
post-2012	5.1	5.3	1.3	0.0	0.90	37	1262	45468
BONDS spreads (logarithm, 50 bp adjustment)								
full sample	5.4	5.5	0.9	0.10	0.63	37	4912	168465
developed countries	4.5	4.2	0.8	0.42	0.24	10	4912	48118
emerging markets	5.8	5.7	0.7	0.21	0.46	27	4912	120347
pre-2007	5.3	5.4	1.1	0.07	0.81	35	2084	66402
2007-2009	5.4	5.4	0.9	0.24	0.73	37	784	28569
2010-2012	5.7	5.6	0.7	0.07	0.83	37	782	27800
post-2012	5.5	5.5	0.8	0.01	0.91	37	1262	45694
CDS spreads (logarithm)								
full sample	4.8	4.8	1.1	0.10	0.72	54	2217	118423
developed countries	4.2	3.9	1.2	0.24	0.60	20	2217	43433
emerging markets	5.2	5.1	0.8	0.12	0.70	34	2217	74990
2007-2009	4.8	4.9	1.2	0.20	0.74	54	521	27045
2010-2012	5.0	5.0	0.9	0.07	0.85	54	782	42127
post-2012	4.7	4.7	1.1	0.01	0.92	54	914	49251

Sources: Bloomberg, JP Morgan, CMA

Notes: Descriptive statistics for pooled variables (unbalanced panel). The upper panel of sovereign spread statistics are given in basis points, the lower panel is natural logarithms. For logarithmic bond spreads statistics are also calculated with an adjustment factor of 50 basis points, which removes negative spreads (see note on the effects of adjustment in the text). Daily data frequency, original sample of 60 countries, time sample: 1 Jan 1999 - 31 Oct 2017. Note that for CDS spreads the sample starts in 2008, so there is no pre-2007 subsample. NX: number of cross-section units that contain valid data of at least half the sample. T: number of time periods with valid data. N: number of valid pooled data points.

First, I use the yield premia of emerging market government bonds issued in dollar and euro with respect to similar maturity US treasuries and German Bunds that are compiled and aggre-

gated into indices by the JP Morgan EMBI Global and EEMBI composites (these composites combine issuances of all outstanding, liquid-traded instruments of each country on a daily basis). These data are accessed through Reuters. Second, I use reference yields of eurozone countries to the Bund at the 5-year maturity sourced from Bloomberg. I collectively refer to these first two yield spreads as sovereign bonds spreads (BOND). Third, I use 5-year sovereign CDS spreads gathered from Bloomberg with the primary source of CMA.

Table A.3 provides descriptive statistics of these series (pooled data). The table reports the variance shares attributable to time series variation (time series deviations from the time series means) and cross-section variation (cross section deviation from the cross-section mean).

Adjustment of bond spreads in log specifications

Bond spreads data include several periods when the yield on some eurozone country bonds occasionally falls below the yields on the risk-free benchmark German Bunds leading to negative bond spreads. Credit risk is naturally a positive quantity, so theoretically negative spread observations would be ruled out. The practical reason for these observations are two-fold. On one hand liquidity of different bond markets may differ distorting yield differences due to credit risk alone. On the other hand, the German Bund is not a perfect proxy for the risk-free rate, an unobserved quantity, and therefore other triple-A issuers may experience yields below the Bund even due to reasons of credit risk differences.

Such negative yields pose questions on how to proceed regarding the log transformation of spreads. The two main approaches are to either discard sample data points where spreads are non-positive or to adjust spreads upwards by an adjustment factor before taking the logarithm. This section briefly considers these possibilities through (i) using original spreads data, (ii) adding 20 basispoints to spreads data (which leads to much less observations to be discarded), and (iii) adding 50 basis points (which resolves all issues of negative spreads).

Discarding data has the obvious shortcoming that it systematically truncates information on the lowest risk issuers. On the other hand adding an adjustment raises the issue of what the adjustment should be, whether it should be time-varying and it leads to a transformation of spreads different from logarithmization. This transformation lies between assessing percentage differences (logs) and nominal differences (linear specification). Although taking logs is prescribed by derivations presented in the main text this derivation only relies on credit risk aspects of bond spreads. As credit risk is naturally a positive quantity, it can be argued that the adjustment of bond spreads is necessary to recover spread components related to credit risk.

As Figure A.7 demonstrates (upper and mid-panels), the original log spreads specification leads to logarithmic forms in the developed group of countries that are much more volatile. Volatility also tends to vary more over time due to time-varying incidence of low outliers. This is due to periods when developed market yields are compressed, and approximate the Bund yields to the 1-2 basispoint range (typically before/after falling into negative territory) their logarithmic spreads pick up large negative values. This results in very large percentage changes

in spreads. The initial adjustment of spreads before taking logs reduces this source of volatility.

A question to ask is how much of the low spreads volatility in the no adjustment case is due to true low credit risk as opposed to other liquidity factors. For an answer we can look at CDS spreads. CDS spreads do not display such low-spread volatility and – especially for developed countries – the means of log CDS spreads are much closer to adjusted log bond spreads than the unadjusted counterpart. Although there are differences between the two markets captured by the CDS - bond basis, this spread is usually negative, indicating that various liquidity factors would reduce CDS spreads relative to bond spreads. Based on this we would observe very low spreads if these spreads truly originated in credit risk.

Figure A.7: Effect of initial adjustment of log bond spreads

Sources: author's compilation based on data from Bloomberg, JP Morgan, CMA.

Notes: Columns calculate logarithm of bond spreads with no prior adjustment (left), with prior 20 basis point adjustment (mid) and with prior 50 basis point adjustment before log transformation. The top panel displays time series of log spreads for developed countries and emerging markets (weekly frequency). The mid-panel shows scatter plot of log spread volatility and log spread levels (country means in four subperiods). The bottom panel shows scatter plots between weekly ratings and log spreads.

The middle panel also shows that the correlation between the volatility and level of log spreads (means of both levels and volatility are shown in four subperiods) was negative in the cases of 0 and 20 basis point adjustments and that it was close to zero in the case of 50 basis

point adjustment.

The bottom panel of the figure suggests a strong, close to linear relationship between log bond spreads and ratings in all cases. However the relationship is stronger (roughly 90 percent as opposed to 70 percent) when spreads are initially adjusted. Linearity is also more pronounced in the adjusted case and the variance of spreads conditional on ratings also appears to be less correlated with ratings.

All these factors weigh toward adjusting bond spreads by 50 basis points before log transformation. Therefore this adjustment is applied in the empirical applications of the thesis and – unless otherwise noted – log bond spreads refer to the variables using this adjustment. (Log CDS spreads and nominal bond spreads are unadjusted unless otherwise noted.)

Statistical tests, time series properties

Table A.4 reports tests results related to time series properties of sovereign credit spreads. Stationarity is assessed on the levels of series by the Advanced Dickey-Fuller (ADF) and the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests at 0-10 period lags. Ljung-Box Q tests and Engle’s LM-test are carried out on the first differences of the series (with 5-10-15 period lags) to test autocorrelation and volatility clustering, respectively. Normality is evaluated by the Jarque-Berra test on first differences. The tables report the share of cross-section units, where respective hypotheses are accepted.

Table A.4: Time series properties of sovereign spreads data (various tests)

	weekly freq.				quarterly freq.			
	BOND	log BOND	CDS	log CDS	BOND	log BOND	CDS	log CDS
Stationarity (Levels)								
ADF (H1) h0 rejected at every lag	0.189	0.000	0.037	0.000	0.027	0.000	0.000	0.000
ADF (H1) h0 rejected at any lag	0.432	0.027	0.111	0.000	0.541	0.027	0.339	0.089
KPSS (H0) h0 accepted at every lag	0.000	0.000	0.000	0.000	0.000	0.000	0.089	0.054
KPSS (H0) h0 accepted at any lag	0.000	0.000	0.222	0.148	0.865	0.865	0.982	0.964
No autocorrelation (Diffs)								
Ljung-Box (H0) h0 accepted at every lag	0.216	0.351	0.148	0.574	0.622	0.838	0.893	0.964
Ljung-Box (H0) h0 rejected at every lag	0.378	0.486	0.370	0.741	0.865	0.973	0.982	1.000
No volatility clustering (Diffs)								
Engle (H0)	0.135	0.243	0.074	0.185	0.486	0.946	0.929	0.946
Normality (Diffs)								
Jarque-Berra (H0)	0.000	0.000	0.000	0.000	0.081	0.486	0.179	0.482
Memo items (Diffs)								
median TS mean	-0.204	-0.001	0.112	0.002	-2.595	-0.007	0.368	0.006
median TS std	23.872	0.061	23.524	0.098	81.610	0.207	51.169	0.321
median TS skewness	0.804	0.580	0.510	0.703	0.453	0.475	0.340	0.503
median TS kurtosis	32.757	10.937	21.045	11.061	7.488	3.814	5.934	4.044

Sources: author calculations.

Notes: The table reports the share of cross-section units (individual country time series), where the hypothesis in the first column is accepted at the 5 percent significance level. ADF and KPSS tests are carried out on 0-10 period lags. Ljung-Box and Engle’s Q tests use 5, 10 and 15 period lags. For these tests the conservative assessment is to require the test returning acceptance at all tested lags and milder conditions are to only require one acceptance. Stationarity tests are performed on levels series, whereas autocorrelation, ARCH, normality tests are carried out on first differences. Memo items at the bottom of the table report medians of individual time series statistics. In case of log bond spreads 50 basis point adjustment is applied.

Table A.5 reports correlations between individual sovereign credit spread time series and the time series of cross-section means. The cross-section means series aim to capture the common component of the time series variation of spreads (this is an alternative to principal components

Table A.5: Sovereign spread comovements: correlations with cross-section means

		BOND					CDS			
	freq.	full	per1	per2	per3	per4	full	per2	per3	per4
levels	D	0.48	0.54	0.96	0.67	0.35	0.54	0.92	0.55	0.03
	W	0.49	0.54	0.96	0.67	0.36	0.54	0.93	0.54	0.04
	M	0.50	0.54	0.97	0.63	0.36	0.50	0.95	0.50	-0.03
	Q	0.50	0.57	0.98	0.73	0.35	0.40	0.94	0.69	-0.18
log levels	D	0.61	0.77	0.96	0.70	0.41	0.72	0.94	0.82	0.47
	W	0.61	0.77	0.96	0.70	0.40	0.71	0.94	0.81	0.46
	M	0.61	0.78	0.97	0.71	0.43	0.71	0.95	0.79	0.51
	Q	0.63	0.79	0.98	0.77	0.42	0.66	0.94	0.82	0.52
diff's	D	0.34	0.23	0.50	0.47	0.51	0.36	0.54	0.35	0.22
	W	0.41	0.28	0.73	0.54	0.53	0.50	0.73	0.40	0.32
	M	0.56	0.39	0.79	0.63	0.53	0.52	0.82	0.48	0.21
	Q	0.59	0.37	0.93	0.69	0.36	0.53	0.92	0.67	0.23
log diff's	D	0.45	0.35	0.56	0.61	0.61	0.58	0.59	0.72	0.46
	W	0.54	0.40	0.64	0.66	0.63	0.73	0.77	0.77	0.54
	M	0.65	0.48	0.78	0.71	0.57	0.79	0.88	0.80	0.54
	Q	0.70	0.53	0.90	0.81	0.56	0.81	0.92	0.87	0.52

Sources: author calculations.

Notes: Median of Pearson's correlations between sovereign spreads and cross-section means. First, for each country separately the cross-sections excluding the country are identified and the mean of this panel is taken for each time period. The recovered time series are the cross-section means series. The correlations are calculated between the individual time series and such cross-section means. The medians of these correlations are reported. Per1: pre-2007, per2: 2007-2009, per3: 2010-2012, per 4: post-2012 subsamples. In case of log bond spreads 50 basis point adjustment is applied.

and I chose to report these statistics, because the first PCA occasionally loads only on a few countries in the sample). Cross-section means are calculated by excluding the given country with which correlations are calculated. The table reports the medians of these correlations in various scenarios.

A.1.3 Sovereign spreads and ratings: additional tables

This subsection adds two more tables to the analysis of the sovereign spreads vs ratings relationship discussed in the main text. These tables provide correlation estimates that complement the visualization of the relationship in the main text.

Table A.6 reports correlations between time series of sovereign credit spreads and time series of sovereign credit ratings. The table reveals that correlations of ratings were generally higher between bond spreads and ratings for the full period compared to correlations between CDS spreads and ratings. The reason for this seems to be that the CDS spread data set does not include the pre-2007 period subsample, where correlations were higher between spreads and ratings. The table also shows that correlations between log spreads and ratings were generally larger than correlations between nominal spreads and ratings.

Table A.7 reports correlations between time series means of sovereign credit spreads and time series means of sovereign credit ratings. Time series means reduces the panel data to one cross-section of spreads and one cross-section of ratings. Correlations are then calculated between these data.

Table A.6: Time series correlations of sovereign spreads and ratings

	freq	spread	median	med L	med H	dev 0.25	dev 0.75	em 0.25	em 0.75	per1	per2	per3	per4
levels	W	BOND	0.51	0.46	0.54	-0.05	0.61	0.35	0.69	0.67	0.11	0.09	0.07
		CDS	0.24	0.15	0.32	-0.35	0.22	0.03	0.49	NaN	0.17	0.16	0.00
	Q	BOND	0.51	0.35	0.66	-0.01	0.61	0.35	0.69	0.73	0.25	0.08	0.04
		CDS	0.09	-0.25	0.48	-0.37	0.16	0.05	0.60	NaN	0.37	-0.00	0.03
log levels	W	BOND	0.53	0.49	0.57	-0.02	0.75	0.36	0.71	0.68	0.15	0.09	0.06
		CDS	0.22	0.15	0.29	-0.30	0.24	0.09	0.55	NaN	0.21	0.19	0.00
	Q	BOND	0.50	0.34	0.65	0.03	0.77	0.34	0.70	0.73	0.28	0.09	0.05
		CDS	0.14	-0.23	0.48	-0.36	0.18	0.04	0.65	NaN	0.45	0.00	0.04
diffs	W	BOND	0.02	-0.03	0.09	-0.07	0.04	0.00	0.05	0.04	0.03	0.03	0.00
		CDS	0.02	-0.03	0.08	-0.05	0.12	0.01	0.04	NaN	0.04	0.01	0.02
	Q	BOND	0.13	-0.12	0.36	-0.23	0.42	0.03	0.32	0.10	0.15	0.08	0.02
		CDS	0.05	-0.19	0.34	-0.00	0.51	-0.11	0.14	NaN	0.18	0.04	0.05
log diffs	W	BOND	0.02	-0.03	0.08	-0.03	0.02	0.01	0.06	0.04	0.03	0.02	0.01
		CDS	0.03	-0.02	0.10	-0.04	0.09	0.01	0.06	NaN	0.07	0.01	0.01
	Q	BOND	0.13	-0.08	0.32	-0.16	0.28	0.01	0.27	0.12	0.07	0.08	0.02
		CDS	0.07	-0.20	0.38	-0.03	0.37	-0.06	0.19	NaN	0.27	0.02	0.08

Sources: author calculations.

Notes: Data are based on Pearson's correlations between sovereign spread and sovereign rating (linear transformation) time series. Aggregates of pairwise (country-by-country) correlations are reported for various data frequencies, for the levels and differences series of both nominal (basis points) and logarithmic spreads. In case of log bond spreads 50 basis point adjustment is applied. The first column reports median of individual country correlations, the next two report the median of the bootstrapped 5 and 95 percent confidence bounds. The next four columns report the 25th and 75 percentile of correlations on the developed country and emerging market samples separately. The last four columns report the medians for time subsamples as in Table A.5.

Table A.7: Cross section correlations of sovereign spreads and ratings

		TIME SAMPLE				
	CX samle	full	per1	per2	per3	per4
BOND	all	0.77	0.63	0.80	0.62	0.72
	developed countries	0.95	0.92	0.84	0.99	0.83
	emerging markets	0.75	0.59	0.71	0.72	0.68
log BOND	all	0.96	0.94	0.93	0.79	0.91
	developed countries	0.99	0.95	0.92	0.94	0.98
	emerging markets	0.88	0.79	0.80	0.79	0.81
CDS	all	0.55	NaN	0.67	0.46	0.65
	developed countries	0.84	NaN	0.69	0.80	0.81
	emerging markets	0.65	NaN	0.63	0.71	0.64
log CDS	all	0.89	NaN	0.90	0.82	0.96
	developed countries	0.96	NaN	0.74	0.91	0.98
	emerging markets	0.86	NaN	0.82	0.82	0.93

Sources: author calculations.

Notes: Pearson's correlations between the time series means of sovereign spreads and time series means of sovereign ratings (linear transformation). The daily data frequency is used to calculate the time series means for the full period or time subsamples (columns, see Table A.5 for definitions of periods). Such means are calculated for the full cross-section of countries and subsamples of only developed and emerging countries. Bond spreads and CDS spreads are taken as input in both nominal levels and logarithmic levels form. In case of log bond spreads 50 basis point adjustment is applied.

A.1.4 Macroeconomic fundamentals data

Table A.8 reports sources and basic information on macroeconomic variables used in the empirical analysis of Chapter 8. Data have been sourced primarily from World Bank and IMF datasets, but I have also used CIA World Factbook data to cross-check quality of data. Several series have been available from multiple data sources. I laid significant emphasis in choosing the exact sources, which had the best properties in terms of both data availability (cross-sectional and time series) and data quality (in many cases there were more than two sources available which permitted to look at which series are consistent with each other; in many cases depiction of time series by country suggested outliers). Only a fraction of the data sources and series that have been used in such analysis are shown in the table. The eventual choice of annual data in case of several variables have been motivated by both of these goals (larger data samples and better data quality) in place of higher frequency counterparts. For some key variables (GDP, Current Account, CPI) I have checked regressions with various measures of the same data.

Table A.8: Macroeconomic data sources

Variable	Source	Orig Freq	Mnemonic
GDP per capita*	WB_DEV	y	NY_GDP_PCAP_PP_CD
CA_CD	IMF_IFS	q	BGS_BP6_USD
RES_CD	WB_GEM	m	TOTRESV
IDS_EDEBT_GNI	WB_IDS	y	DT_DOD_DECT_GN_ZS
IDS_EDEBTSERV_EXP	WB_IDS	y	DT_TDS_DECT_EX_ZS
GEDEBT_CD	WB_EDEBT	q	DT_DOD_DECT_CD_GG_AR_US
Govt Debt/GDP*	IMF_HISTDEBT	y	GGXWDG_GDP
GDP_KN	WB_GEM	q	NYGDPMKTPSAKN
GDP_CD	WB_GEM	q	NYGDPMKTPSACD
CPI	WB_GEM	m	CPTOTSAXN
WDI_CA_GDP	WB_DEV	y	BN_CAB_XOKA_GD_ZS
Private Credit/GDP*	WB_DEV	y	FS_AST_PRVT_GD_ZS
WDI_GDP_yoy	WB_DEV	y	NY_GDP_MKTP_KD_ZG
Fin Dev Index*	IMF_FINDEV	y	FD_FD_IX
WEO_GDEBT_GDP	IMF_WEO	y	GGXWDG_NGDP
WEO_GDP_yoy	IMF_WEO	y	NGDP_RPCH
Fiscal Bal/GDP*	IMF_WEO	y	GGXCNL_NGDP
2yr proj Fisc Bal /GDP*	IMF_WEO	y	GGXCNL_NGDP
CPI inflation yoy*	IMF_WEO	y	PCPIEPCH
BANK_NPL	IMF_FSI	y	FSANL_PT
BANK_ROE	IMF_FSI	y	FSERE_PT
BANK_LIQ	IMF_FSI	y	FSKRC_PT
WGI Corruption*	WB_WGI	y	CC_EST
WGI Govt Effect*	WB_WGI	y	GE_EST
WGI Pol Stab*	WB_WGI	y	PV_EST
WGI Rule of Law*	WB_WGI	y	RL_EST
WGI_RQUAL	WB_WGI	y	RQ_EST
WGI_VOIC	WB_WGI	y	VA_EST
GDP_KN4q	derived		GDP_KN sum last 4Q
RGDP_yoy*	derived		GDP_KN4q yoy
GDP_CD4q	derived		GDP_CD sum last 4Q
GDP_CD12m	derived		GDP_CD4q spline month
CA_GDPq	derived		CA_CD/GDP_CD
Curr Acct Bal/GDP*	derived		CA_GDPq sum last 4 Q
Intl Reserves/GDP*	derived		RES_CD/GDP_CD12m
EDEBT_GDP	derived		EDEBT_CD/GDP_CD4q
Govt Ext. Debt/GDP*	derived		GEDEBT_CD/GDP_CD4q
CPI_qoq	derived		CPI logdiff
FX Debt/GDP*	combined		FXDEBT

Sources: WB: World Bank (DEV: World Development Indicators, GEM: Global Economic Monitor, ISD: International Debt Statistics, EDEBT: Joint External Debt Hub, WGI: Worldwide Governance Indicators); IMF: International Monetary Fund (HISTDEBT: Historical Public Debt, IFS: International Financial Statistics, WEO: World Economic Outlook, FINDEV: Financial Development Index, FSI: Financial Soundness Indicators), Bloomberg.

Notes: Variables included in main text regressions are marked with an asterisk (latest available published data are used). Abbreviations: CD: Current dollars, KN: Constant dollars, CA: current account balance, RES: international reserves, EDEBT: external debt, GDEBT: Gov't debt, NPL: non-performing loans, ROE: return on equity, LIQ: liquidity, RQUAL: Regulatory Quality, VOIC: Voice and Accountability. FX debt to GDP are calculated based on the dataset by [Arslanalp and Tsuda \(2014\)](#) augmented with data for developed countries from Bloomberg.

A.2 Historical data set

This section describes the historical data set that is used primarily to calibrate parameters of the sovereign credit risk model and to test some of the model predictions. The most important trade off in data collection involves choosing either a recent time sample (where much more fundamental data are available at higher frequencies) or choosing historical data (where much less series are available, usually annual data, but at a long time horizon). Because crises occur infrequently and have a relatively long duration, it is the time series dimension that constitutes the real bottleneck. I opted therefore to use annual historical data to calibrate parameters of the model.

Table A.9: Descriptive statistics of historical data (pooled data, full sample)

	mean	st.dev.	median	interq. range	perc.5	perc.95	N	data sources
$\bar{g}$	3.8	2.4	3.5	2.9	0.3	7.8	4230.0	KRV
y_gap	-0.2	5.2	-0.1	4.4	-7.4	6.9	4333.0	KRV
g	3.8	5.1	4.0	4.6	-3.8	10.6	6092.0	KRV, WEO
$\log(gdppc)$	8.8	1.2	8.9	2.0	6.6	10.6	3905.0	WEO
r_TB	0.5	9.2	2.1	6.2	-15.4	10.7	1049.0	KRV
r_D	2.5	17.2	2.2	7.6	-15.2	19.2	1189.0	KRV
$\Delta \log(e)$	8.7	46.3	1.1	10.9	-11.6	50.6	4166.0	KRV, WEO
res	10.0	15.8	6.0	8.4	0.7	29.8	4059.0	KRV
ca	-3.2	11.7	-2.5	6.8	-16.9	9.8	5649.0	KRV, WEO
$pdebt$	56.4	60.3	30.2	71.9	3.6	175.4	5284.0	GDD
$gbal$	-3.6	6.0	-3.1	5.2	-12.9	4.4	5319.0	KRV, WEO
$grev$	26.3	13.5	23.4	17.6	9.7	49.4	5187.0	KRV, WEO
$gexp$	29.5	12.8	27.4	18.3	12.7	51.8	5156.0	KRV, WEO
$gdebt(d)$	54.1	58.0	42.6	42.8	9.4	129.3	4408.0	RRb, WEO
$\Delta(d)$	0.1	21.3	0.1	5.6	-12.8	12.9	4267.0	RRb, WEO
$ext.share(\psi)$	33.2	28.4	25.2	50.7	0.0	83.5	3388.0	RRa
$icrg$	60.0	13.0	61.5	17.3	37.0	78.4	2064.0	AT
$pol.crisis$	0.3	0.5	0.0	1.0	0.0	1.0	6398.0	CSP, POLITY IV
$curr.crisis$	0.2	0.4	0.0	0.0	0.0	1.0	3565.0	RRb
$bank.crisis$	0.1	0.3	0.0	0.0	0.0	1.0	3570.0	RRb
$syst.crisis$	0.1	0.3	0.0	0.0	0.0	1.0	4128.0	LV
g^{US}	3.0	2.1	3.2	2.6	-0.6	6.2	7000.0	KRV, WEO
r_D^{US}	6.1	2.8	6.0	2.8	1.3	12.0	3750.0	KRV
g^{REG}	4.3	2.4	4.4	2.5	0.3	8.6	7000.0	KRV, WEO

Sources: Based on the data sets of [Kaminsky, Reinhart and Végh \(2004\)](#) (KRV) which references IMF WEO, IMF IFS, IMF GFS data, [Reinhart and Rogoff \(2011a\)](#) (RRa), [Reinhart and Rogoff \(2011b\)](#) (RRb), [Asonuma and Trebesch \(2016\)](#) (AT), [Laeven and Valencia \(2012\)](#) (LV), IMF WEO, IMF GDD; CSP and POLITY IV.

Notes: Descriptive statistics for pooled variables (unbalanced panel). Annual data frequency, 125 countries, time sample: 1960-2017. Variables: $\bar{g}$: real GDP trend growth rate; y_gap : cyclical component of real GDP to trend; g : real GDP growth rate; $\log(gdppc)$: log of per capita GDP (constant USD); r_{TB} : real treasury bill rate; r_D : real discount rate; $\Delta \log(e)$: real exchange rate (percent change); res : international reserves to GDP; ca : current account balance to GDP; $pdebt$: private sector debt to GDP; $gbal$: general or central government balance to GDP; $grev$: general or central government revenues to GDP; $gexp$: general or central government expenditures to GDP; $gdebt(d)$: general or central government debt to GDP; $ext.share(\psi)$: external share of government debt; $\Delta \log(d)$: government debt ratio, percentage point change; $icrg$: ICRG political risk ratings (higher score: lower risk); $pol.crisis$: a binary indicator with value of one if any occurred: coup (CSP COUP), major civil violence or civil war (CSP MVEP), political regime change (POLITY IV); $curr.crisis$: currency crisis; $bank.crisis$: banking crisis; $syst.crisis$: systemic banking crisis. g^{US} : US real GDP growth rate; r_D^{US} : US nominal discount rate; g^{REG} : mean of real GDP growth rates in the region;

I compiled my historical data set relying on several sources. I commenced by joining various data sets to the one provided by [Kaminsky, Reinhart and Végh \(2004\)](#). [Kaminsky, Reinhart and Végh \(2004\)](#) compiled a large number of macroeconomic series originally from IMF WEO, IFS and GFS databases. Of these I use nominal, real GDP data in national currency and USD,

current account and fiscal balance figures, fiscal revenues and expenditures, various interest rates and reserves in the thesis as well as the trend cycle decomposition of real GDP available in this source. A huge benefit of the [Kaminsky, Reinhart and Végh \(2004\)](#) data is its scope: it is available for 104 countries for the period between 1960-2003. I augmented the original macro data set by IMF WEO data in time (up to 2017) and in cross-section (mainly adding much of the post-socialist world that was missing).

I joined crisis and debt ratio data sets of [Reinhart and Rogoff \(2011b\)](#) and [Laeven and Valencia \(2012\)](#), data on various aspects of debt restructuring in [Cruces and Trebesch \(2013\)](#) and [Asonuma and Trebesch \(2016\)](#) as well as the ICRG political risk ratings available in [Asonuma and Trebesch \(2016\)](#), data on external share of debt by [Reinhart and Rogoff \(2011a\)](#). Various aspects of political crisis come from the Center for Systemic Peace (data on coups and major civil violence) and the POLITY IV database (political regime changes). IMF program dates come from the compilation of [Dreher and Rupperecht \(2007\)](#). I also use data on private sector debt outstanding provided recently by [Mbaye, Badia and Chae \(2018\)](#).

Table A.10: Descriptive statistics of historical data (pooled, subsamples)

	A: NON-CRISIS					B: FINANCIAL CRISIS					B: SOVEREIGN DEBT CRISIS				
	median	iqr	p5	p95	N	median	iqr	p5	p95	N	median	iqr	p5	p95	N
$\bar{g}$	3.5	2.7	0.4	7.3	1980.0	2.9	2.4	-0.3	5.9	496.0	2.5	2.5	-1.0	6.1	615.0
y_gap	0.1	4.1	-7.0	7.2	1980.0	-0.6	4.7	-7.9	5.7	496.0	-0.9	5.7	-9.6	6.9	620.0
g	4.2	4.4	-2.7	10.7	3242.0	3.5	4.9	-5.7	9.2	650.0	3.0	5.7	-7.9	10.1	699.0
$\log(gdppc)$	9.3	2.0	6.6	10.6	2234.0	8.2	1.4	6.4	9.5	548.0	7.8	1.3	6.4	9.1	581.0
r_{TB}	2.3	5.5	-8.3	9.6	593.0	1.9	14.1	-29.6	12.4	99.0	-2.8	21.5	-41.7	12.8	104.0
r_D	1.8	5.8	-6.9	13.0	571.0	5.9	11.9	-20.8	48.7	151.0	2.4	22.8	-54.3	37.4	206.0
$\Delta \log(e)$	0.6	8.8	-13.4	24.6	1980.0	5.6	18.5	-14.2	81.6	496.0	9.9	37.2	-14.2	177.4	609.0
res	7.3	10.7	1.0	41.5	1892.0	5.3	7.7	0.2	26.2	493.0	4.4	6.6	0.2	17.3	612.0
ca	-2.3	7.6	-18.0	11.2	3236.0	-3.5	6.3	-14.6	5.1	651.0	-3.3	6.6	-17.4	5.5	686.0
$pdebt$	47.4	91.5	4.5	183.4	2822.0	21.7	28.1	2.9	107.4	553.0	16.3	19.5	2.1	61.4	537.0
fb	-2.7	5.0	-12.6	5.7	2949.0	-3.3	4.6	-12.1	2.9	627.0	-3.8	6.0	-15.2	3.2	658.0
$grev$	26.0	19.9	10.4	50.8	2882.0	20.9	12.2	9.5	38.8	623.0	19.0	10.1	9.3	35.1	650.0
$gexp$	29.6	20.6	13.2	52.9	2879.0	24.9	13.5	13.1	42.6	625.0	22.7	11.3	13.0	43.4	653.0
$gdebt(d)$	42.0	38.9	9.8	130.7	2418.0	57.7	49.9	13.1	143.8	430.0	68.6	58.4	15.8	201.3	454.0
$\Delta(d)$	-0.1	5.2	-10.5	9.5	2366.0	0.2	12.0	-20.9	23.1	416.0	-0.6	16.9	-41.1	43.4	434.0
$ext.share(\psi)$	22.7	51.0	0.0	84.2	1571.0	44.8	58.5	0.0	88.9	347.0	41.7	55.1	2.0	87.2	411.0
$icrg$	64.1	16.4	35.9	80.0	947.0	58.7	15.2	37.3	74.5	422.0	53.4	15.1	36.5	67.9	482.0
$pol.crisis*$	0.3	0.4	0.0	1.0	3216.0	0.3	0.5	0.0	1.0	655.0	0.5	0.5	0.0	1.0	693.0
$curr.crisis*$	0.0	0.0	0.0	0.0	1471.0	0.3	0.5	0.0	1.0	335.0	0.4	0.5	0.0	1.0	478.0
$bank.crisis*$	0.0	0.0	0.0	0.0	1472.0	0.3	0.4	0.0	1.0	335.0	0.2	0.4	0.0	1.0	480.0
$syst.crisis*$	0.0	0.0	0.0	0.0	2316.0	0.2	0.4	0.0	1.0	574.0	0.2	0.4	0.0	1.0	590.0
g^{US}	2.7	2.4	-0.6	5.4	3616.0	3.5	2.0	-0.4	5.4	671.0	3.6	1.6	-0.3	6.4	733.0
r_D^{US}	6.0	2.6	1.3	12.0	1925.0	6.0	2.5	1.3	12.0	432.0	6.0	2.0	2.0	12.0	493.0
g^{REG}	4.6	2.5	0.3	8.0	3616.0	3.5	2.3	0.9	5.9	671.0	3.4	2.5	0.8	5.8	733.0

Sources: Based on the data sets of [Kaminsky, Reinhart and Végh \(2004\)](#), [Reinhart and Rogoff \(2011a\)](#), [Reinhart and Rogoff \(2011b\)](#), [Asonuma and Trebesch \(2016\)](#), [Laeven and Valencia \(2012\)](#), IMF WEO, IMF GDD; CSP and POLITY IV as described in Table A.9.

Notes: Non-crisis data sample (Panel A) includes country-year observations, where financial crisis and sovereign debt crisis are not recorded. The financial crisis sample (Panel B) includes country-year observations, where currency or banking crisis variables of ([Reinhart and Rogoff, 2011b](#)) have a value greater than 0 or where systemic banking crisis is recorded ([Laeven and Valencia, 2012](#)). Sovereign debt crisis country-year samples are identified where [Reinhart and Rogoff \(2011b\)](#) records either external or domestic sovereign crisis and between default start and end dates in [Cruces and Trebesch \(2013\)](#). For variable definitions see notes in Table A.9. *: for crisis indicators, the mean and standard deviation are shown instead of the median and the interquartile range.

Altogether my data set spans annual data for 125 countries on the 1970-2010 time sample.

Table A.9 contains descriptive statistics on key variables used in Chapter 5. Table A.10 provides descriptive statistics on variables in subsamples representing normal times (no currency crisis, no sovereign debt crisis, no bank crisis), financial crisis (either of currency, banking crisis as defined by [Reinhart and Rogoff \(2011b\)](#), or systemic banking crisis as defined by [Laeven and Valencia \(2012\)](#)), sovereign debt crisis (either of external or domestic sovereign crisis as

Table A.11: Output loss and bank loss proxies – descriptive statistics and correlations

	mean	std	median	p5	p95	N
descriptives						
cumulative output loss	30.7	33.8	23.3	0.0	105.0	133.0
annual output loss	9.9	11.5	6.9	0.0	32.4	131.0
recap/GDP	7.6	9.4	4.2	0.2	31.2	57.0
fiscal cost/GDP	12.7	12.6	8.7	0.7	42.9	90.0
NPL/GDP proxy	27.1	58.2	11.3	0.8	113.4	85.0
liq.assist/GDP proxy	19.5	49.8	6.4	0.3	90.1	82.0
correlations with output loss						
recap/GDP	0.4	0.2	0.4	0.1	0.6	1000.0
fiscal cost/GDP	0.3	0.1	0.3	0.0	0.5	1000.0
NPL/GDP proxy	0.1	0.1	0.1	-0.1	0.4	1000.0
liq.assist/GDP proxy	0.2	0.2	0.2	-0.1	0.4	1000.0

Sources: Based on the data set of [Laeven and Valencia \(2018\)](#).

Notes: [Laeven and Valencia \(2018\)](#) reports cumulative output loss data on systemic banking crises. These output losses are divided by the duration of crisis episodes for the annual measure. Other variables in the table are related to banking sector losses. The upper panel provides descriptive statistics, the bottom panel provides bootstrap correlation statistics (bootstrap sample of 1000). Recap/GDP: recapitalization of banks; fiscal cost/GDP: gross direct fiscal outlays related to bank restructuring; NPL/GDP proxy: computed as the quotient of peak NPL in terms of total loans and an estimate of the financial sector size to GDP (itself the quotient of the fiscal cost to GDP and fiscal cost to financial sector assets variables reported by the authors); liq.assist/GDP proxy: quotient of liquidity support to total deposits and the estimate of the financial sector size to GDP.

Figure A.8: Debt relief vs haircut market value

Sources: author's compilation based on [Asonuma and Trebesch \(2016\)](#).

Notes: The figure plots haircut NPV's in bond restructurings as defined by [Asonuma and Trebesch \(2016\)](#) (h^m) against debt relief (h^g) for cases when $h^g > 0$ and the market haircut estimate based on the equation $\hat{h}^m = 0.25 + 0.75h^g$.

defined by [Reinhart and Rogoff \(2011b\)](#), or debt restructuring periods as defined by [Cruces and Trebesch \(2013\)](#) and [Asonuma and Trebesch \(2016\)](#)). Although there are differences in crisis identification across authors, the key benefit of merging these data sets is that it significantly reduces the number of missing data in the data set.

Table A.11 provides descriptive statistics of output losses and banking sector losses based on

data in [Laeven and Valencia \(2018\)](#). The model in Chapter 5 assumes that defaults lead to output losses through bank losses (writedowns) on sovereign debt securities. Direct measures of such writedowns for individual countries and crisis events are not available. However [Laeven and Valencia \(2018\)](#) reports several variables related to bank losses within systemic banking crisis, which may give a (rough) indication as to its relation with output losses. Notably though, all of the related variables are noisy approximations for shocks to banks. This necessarily downwardly biases correlation coefficients compared to true correlations.

The following measures are used to proxy bank losses: the authors report recapitalization losses. Recapitalization is expected to be higher when bank losses are larger, although the fiscal capacity and willingness to save banks are important factors which determine the strength of this link. The same is true for reported fiscal outlays related to the bank crisis. Peak NPL is another measure of banking sector problems, but again several other factors (such as the business model² or past problems with the balance sheet) besides current adverse shocks may influence. Both of the latter variables also need to be transformed to be denominated in GDP terms instead of total loans or total deposits. The transformation method introduces another source of noise, since the variable I have available (fiscal costs to GDP/fiscal cost to total financial sector assets, which yields financial sector assets/GDP) is only a rough approximation for loans/GDP or deposits/GDP.

Figure A.8 shows how the estimation of haircut market value by debt relief with the equation used in Chapter 5 compares to actual observations. As seen from the plot, the chosen functional form provides a reasonable fit.

²Some banks work in environments with constantly higher credit risk and charge higher spreads in compensation. This leads to high NPL but does not necessarily cause capital or P&L problems.

A.3 Empirical tests of the theoretical models

In this section I also use historical data set described above to investigate some of the more fundamental assumptions and some of the predictions of the models in Chapters 5 and 6. To be useful for this purpose I need to identify both sovereign default periods and funding liquidity crisis periods, the states that the model operates with. I identify sovereign defaults as the country-year observations where [Reinhart and Rogoff \(2011b\)](#) records either external or domestic sovereign crisis. I also add default periods identified in [Cruces and Trebesch \(2013\)](#), because the former data set is shorter and excludes some countries and because there are useful additional variables the latter authors report.

Table A.12: Transition matrix: normal, default and funding crisis spells

from into	Normal Repay (NR)	Normal Default (ND)	Funding Crisis Repay (CR)	Funding Crisis Default (CD)
Normal Repay (NR)	2673	31	92	10
Normal Default (ND)	28	348	10	0
Funding Crisis Repay (CR)	94	7	391	27
Funding Crisis Default (CD)	9	0	24	224

Sources: author calculations based on [Dreher and Rupperecht \(2007\)](#), [Reinhart and Rogoff \(2011b\)](#), [Cruces and Trebesch \(2013\)](#), [Asonuma and Trebesch \(2016\)](#) data.

Notes: The table displays a transitions matrix of four states (cells report the number of instances that a row state spell precedes a column state spell): normal repayment periods (NR); default occurring that begins outside of a funding crisis (ND); funding crisis with repayment (CR); that begins with an on going funding crisis default (CD). A funding crisis is assumed to start when a country turns to the IMF for an SBA program (data from [Dreher and Rupperecht, 2007](#)) and ends when it returns to market funding (data from [Asonuma and Trebesch, 2016](#)) or the IMF program ends.

I identify a funding crisis as a period that starts when a country turns to the IMF for a Stand-By Agreement program (data from [Dreher and Rupperecht, 2007](#)) and ends when it returns to market funding (data by [Asonuma and Trebesch, 2016](#)) or the IMF program ends. There were cases when a country faced funding problems and either decided not to turn to the IMF or received funding from other sources and there were also cases when SBA programs were initiated with access to market funding. Nevertheless, SBA programs have historically been the main vehicle for helping governments that faced imminent funding problems, so SBA program initiation is likely to be a good indicator of such difficulties arising.³

In my opinion the initiation of SBA programs are a better gauge for funding problems than loss of market access proxied by lack of international loan/bond issuances as done by [Asonuma and Trebesch \(2016\)](#) for instance. No international issuance may often be a result of no foreign currency funding need.⁴ These cases constitute cases of no demand for funds rather than no

³Although available from the same source ([Dreher and Rupperecht, 2007](#)) I do not add other IMF/World Bank programs, because those tend to be applied for more long-term structural adjustments. SBA program constitute the majority of programs.

⁴There are many such cases. First, many governments use domestic funding markets (e.g. most countries of the advanced world issue bonds domestically and do not tap international bond markets, but this is clearly not because they are funding-constrained; significant state asset sales or central bank funding could also at times cause countries to stay away from using international bond markets). In addition, there are several countries (though the

supply of funds.

Although a good proxy for initial liquidity problems, SBA programs are not a good proxy for the duration of market exclusion, because SBA programs have a predetermined duration (2-3 years) and so they may end later than the time when government could already access the market. Also governments often do not rush back to market funding, because IMF interest rates are preferential, i.e. lower than what would be available in the market. Governments also often decide to wait until investor appetite for bonds are more likely to have returned rather than risk unsuccessful issuance, which could undermine exiting the program. For this reason, I use a combination of two data sources and identify the end of a funding crisis spell by whichever happens before: the market is re-accessed by an international issuance (using the data of [Asonuma and Trebesch, 2016](#)) or the SBA program is concluded.

Table [A.12](#) reports transitions from a normal repayment period (NR), a default that occurs without a funding crisis ongoing in the year of the default announcement (ND), a funding crisis without a default (CR) and a default with a funding crisis (CD). As the table shows, there were many spells with funding crises when a country chose to repay and eventually exited back into the normal repayment state instead of exiting into a default state. This state of being excluded from markets without defaulting is absent from the current sovereign debt literature: extant studies presume that exclusion is a consequence of a default.

Having provided definitions for these spells I turn to an analysis of the factors that are associated with moving from one state to the other. This analysis is tentative regarding causality, but statistical association can still indicate whether changes in various fundamentals are consistent or are at odds with theory. There are two questions this empirical analysis seeks to address: (1) what factors predict entering a crisis/default spell and (2) what are the observed outcomes of a crisis/default spell.

What predicts default and liquidity crisis spells?

Table [A.13](#) reports medians in the normal repayment (NR) state and medians in periods prior to normal default (ND), funding liquidity with repayment (CR) and default (CD) episodes. Kruskal-Wallis tests are also reported to determine for which variables do medians significantly differ (significant differences highlighted), i.e. which variables differed before crisis periods significantly from repayment periods.

Based on the table, countries had lower trend growth rates before default spells, which is consistent with theory. Real (domestic) interest rates were on the other hand not significantly higher, but as discussed before available proxies for real interest rates are problematic.

Government deficits were higher and debt tended to climb higher before both types of default episodes, though significantly more so in defaults within funding liquidity crisis spells (CR rather than NR). This is indicative of a sustainability aspect (and so ability to repay rather than

minority) that simply do not have significant government debt or the foreign-currency part of debt are long-term issues. These governments do not need to access international bond markets every year.

Table A.13: Normal repayment vs pre-spell periods: medians and Kruskal-Wallis tests

	MEDIAN				MEDIAN DIFFERENCES			
	NR	ND	CR	CD	ND-NR	CR-NR	CD-NR	CD-CR
$\bar{g}$	3.30	2.75	3.43	2.09	-0.55	0.14	-1.21	-0.68
g	3.90	3.69	3.97	2.48	-0.21	0.07	-1.42	-0.28
g^{REG}	4.44	3.22	3.74	3.16	-1.22	-0.70	-1.28	-0.52
$\log(gdppc)$	9.22	8.14	8.54	7.70	-1.08	-0.68	-1.51	-0.40
r_{TB}	1.90	1.37	1.21	-2.17	-0.54	-0.70	-4.08	0.16
i_D^{US}	6.33	7.63	5.75	8.58	1.30	-0.58	2.26	1.88
$\Delta \log(e)$	1.39	6.96	3.90	0.29	5.57	2.51	-1.09	3.06
res	6.06	4.22	4.91	3.95	-1.84	-1.15	-2.11	-0.69
ca	-2.63	-3.07	-4.48	-4.73	-0.44	-1.85	-2.10	1.41
fb	-3.04	-5.27	-3.88	-4.40	-2.22	-0.83	-1.35	-1.39
$gdebt(d)$	40.57	49.85	37.06	43.65	9.28	-3.51	3.08	12.79
$ext.share(\psi)$	27.42	43.59	38.35	55.14	16.16	10.92	27.72	5.24
$ext.gdebt(\psi d)$	8.93	13.87	12.71	26.44	4.94	3.79	17.51	1.16
$dom.gdebt * pdebt$	11.79	5.11	4.18	5.17	-6.67	-7.60	-6.62	0.93
$\Delta(d)$	0.04	1.06	0.11	3.89	1.01	0.07	3.85	0.94
$icrg$	62.93	54.75	61.82	57.78	-8.18	-1.11	-5.15	-7.07
$pol.crisis*$	0.30	0.55	0.36	0.36	0.25	0.06	0.06	-0.19
$curr.crisis*$	0.00	0.33	0.26	0.25	0.33	0.26	0.25	-0.06
$bank.crisis*$	0.00	0.18	0.17	0.22	0.18	0.17	0.22	-0.01
$syst.crisis*$	0.00	0.06	0.15	0.20	0.06	0.15	0.20	0.09

Sources: as described in previous tables.

Notes: The table displays variable medians in normal repayment periods (NR) and pre-spell periods of ND, CR, CD spells (based on average values in the three periods prior to the start of the spell). Spells are as described in Table A.12. Bootstrap statistics are used due to small sample size. For variable definitions see notes in Table A.9. (*): for crisis indicators, the mean is reported instead of the median.

The left panel of the table displays median (and mean) differences. These are evaluated for significance using Kruskal-Wallis (in (*): ANOVA) tests. Dark shading stands for significance at 1 percent, light shading at 5 percent.

a willingness to repay motive) of defaulting.

In line with the assumptions of the model, low official reserves raise the probability of funding liquidity crisis spells, as periods preceding funding crisis spells (both CR and CD) had significantly lower reserves than normal repayment periods.

A country entering a funding crisis spell was more likely to default (CD) rather repay (CR) if growth was low and debt was spiralling higher, perhaps deemed to be already out of control in these instances.

Political instability seems more relevant for pre-ND than pre-CR and pre-CD periods. Medians reveal that ICRG was lower (signalling higher risk) prior to both cases of default than repayment cases.

Government debt ratios tended to be higher before spells than in normal repayment times, but the difference was not significant statistically. On the other hand, default spells were more characteristic of countries with higher external debt share, high external debt ratios and lower domestic debt ratios, clearly in line with model assumptions.

Defaults and funding crisis were also associated with lower income countries as seen by GDP capita levels, however, this is not too informative given that economic development is correlated with several fundamental determinants related to the default decision.

External factors could also have played a role as both regional growth rates were lower and

Figure A.9: Kernel densities of fundamentals in normal repayment and pre-crisis spells

Sources: author's compilation.

Notes: Each subplot in the figure shows ...

US interest rates were higher before spells compared with normal repayment times.⁵

Having said that, the Figure A.9 cautions that there is very large dispersion surrounding central tendencies. The figure also displays discernible mean/median differences of default spells and normal repayment times regarding development levels, external shares of public debt, lower political stability and (in case of CD spells) higher debt dynamics and lower real growth. However, it is also evident from full distributions in these plots that neither of these characteristics are close to being perfect separators of normal and default times.

Table A.14 investigates predictions of the models in the chapter using probit regressions. In these regressions the dependent variable is an indicator of transition into default spells (vs remaining in normal repayment) and explanatory variables are pre-crisis fundamentals. The benefit of such multivariate analysis is that it is able to separate partial effects, but unfortunately

⁵Currency and banking crises were more prevalent before all three spells than in normal repayment times, but this is due to definition: normal repayment times do not include periods with such crisis. The rationale for this exclusion is that potential false negative funding crisis spells (in which spells financial crises are prevalent) would spuriously add such crisis data to normal repayment periods. To err on the side of caution by making normal periods even more normal, I define normal periods as ones without a default spell as well as without currency and banking crisis spells.

Table A.14: Probit regressions of transition into default

Regr. spec	(A) literature		(B) ext.debt		(C) dom.debt		(D) politics	
Dependent	$1_{R \rightarrow D}$		$1_{R \rightarrow D}$		$1_{R \rightarrow D}$		$1_{R \rightarrow D}$	
Regressors	coef	se.	coef	se.	coef	se.	coef	se.
$\Delta rgdp_t$	-0.086***	(0.017)	-0.070***	(0.025)	-0.049*	(0.027)	-0.078***	(0.024)
$\Delta rgdp_{t-1}$	-0.049**	(0.019)	-0.064***	(0.024)	-0.093***	(0.028)	-0.068***	(0.022)
$gdebt_{t-1}$	0.000	(0.001)	-0.005*	(0.003)			-0.003**	(0.001)
$ext.gdebt_{t-1}$			0.013**	(0.005)	0.001	(0.003)		
$ext.share_{t-1}$			0.000	(0.003)				
$(dom.gdebt * pdebt)_{t-1}$					-0.016**	(0.006)		
$\log(gdppc_{t-1})$					-0.254***	(0.093)	0.080	(0.084)
$pol.crisis_{t-1}$							0.405	(0.281)
$pol.icrg_{t-1}$							-0.035**	(0.014)
constant	-1.709***	(0.110)	-1.626***	(0.203)	0.795	(0.828)	-0.252	(0.834)
McFadden R-squared	0.130		0.133		0.229		0.229	
Obs with Dep=1	37		27		16		16	
No. observations	2012		1258		829		872	

Sources: as described in previous tables.

Notes: The table displays medians of variables in normal repayment periods (NR) as well as variable medians of pre-spell periods (average value in the three periods prior to the start of the spell). Spells are: default outside of a funding crisis (ND), funding crisis with repayment (CR), funding crisis and default (CD) as described in Table A.12. Bootstrap statistics are used due to small sample size. For variable definitions see notes in Table A.9. *: for crisis indicators, the mean is reported instead of the median.

The left panel of the table displays median (and mean) differences. These are evaluated for significance using Kruskal-Wallis (and ANOVA) tests. Dark shading stands for significance at 1 percent, light shading at 5 percent.

adding variables significantly reduces sample size due to missing values.⁶

The first specification reproduces the basic formulation of the quantitative literature in which government decides on defaulting based on the outstanding debt ratio (neglecting however debt valuation) and growth shocks. As predicted by this literature, low past growth and a more adverse growth shock raises the probability of observing a default. However, in contrast to the prediction of this literature the government debt ratio is statistically insignificant.

The second specification adds variables related to external debt. As the models predict, external debt is a significant positive factor, whereas government debt ratio also becomes significant but with a negative sign. The models in the chapter have a ready explanation for such a finding: defaulting on high domestic debt is less likely because governments fear that this would result in output losses, however defaulting on external debt may be beneficial if debt service costs are high.

The third specification adds specifically a domestic debt ratio variable interacted with private debt-to-output as a proxy of financial deepening and finds it to have the predicted negative sign. The specification also includes per capita GDP level to control for development level in general. Higher per capita output does significantly reduce the probability of default, but the domestic debt variable remains also significant.

The final specification looks at the role of political factors. Adding two political proxies to the original equation again results in negative government debt effects and growth shocks are significant negative. A lower ICRG index (higher political instability) significantly raises default probability, though having a political crisis is not significant. Per capita output loses its

⁶More precisely it is missing values non-overlapping across variables that raise dropped observations compared to more parsimonious specifications.

significance, perhaps indicating that development level was significant through its correlation with political stability.

In sum, empirical data are consistent with model assumptions and predictions. Moreover they support extensions of the model relative to mainstream quantitative models: that (even controlling for per capita GDP differences) a hostile political-institutional environment is a predictor for a default; that defaults are less likely in countries with large domestic debt markets and more likely in ones which issue debt internationally.

What characterizes default and liquidity spells?

Table A.15: Median paths compared to pre-spell periods

	Normal Default (ND)			Funding crisis Repay (CR)			Funding crisis Default (CD)		
	per1	perF	post	per1	perF	post	per1	perF	post
$\bar{g}$	-0.22	0.12	0.40	-0.02	-0.03	-0.07	0.00	0.31	0.54
g	-2.96	-1.06	0.04	-0.90	-0.40	0.29	-2.26	-0.16	1.86
g^{REG}	-0.12	0.04	0.21	-0.28	-0.15	0.03	-0.20	-0.02	0.51
$\log(gdppc)$	-0.09	-0.11	-0.12	-0.03	-0.03	-0.04	-0.10	-0.13	-0.16
r_{TB}	0.47	1.32	1.12	-1.87	-1.50	-0.85	-10.85	-11.53	-1.60
r_D	2.16	-1.00	-5.46	-3.22	-2.42	4.06	-14.21	-9.48	8.55
$\Delta \log(e)$	7.13	9.37	-4.14	1.43	-1.87	0.49	44.17	37.98	38.14
res	-1.80	-2.60	0.25	0.49	0.77	0.04	-0.17	-1.11	1.54
ca	1.01	0.88	0.48	1.97	1.72	1.22	1.79	1.01	0.82
fb	-0.48	0.29	2.03	0.77	0.60	0.73	1.51	1.76	2.78
$gdebt(d)$	7.28	14.83	-8.72	2.61	3.27	6.83	31.95	24.17	0.20
$ext.share(\psi)$	1.72	2.34	-0.16	2.13	1.95	2.62	1.61	3.42	4.75
$ext.gdebt(\psi d)$	4.27	3.81	-0.90	2.61	3.11	5.04	16.59	17.47	7.79
$dom.gdebt$	1.37	-0.58	-9.45	-0.31	-0.10	-2.50	12.35	8.33	-7.79
$\Delta(d)$	1.81	-1.54	-4.91	0.07	-0.30	-0.06	8.56	0.94	-5.21
$icrg$	-3.43	-4.12	-4.77	-0.32	-0.41	-2.55	-3.63	-3.36	-4.42
$pol.crisis^*$	-0.02	-0.04	-0.06	0.04	0.06	-0.00	0.11	0.02	0.05
$curr.crisis^*$	0.10	0.05	-0.09	0.05	0.04	-0.03	0.25	0.22	0.03
$bank.crisis^*$	0.07	0.06	0.04	0.09	0.09	0.06	0.20	0.13	0.01
$syst.crisis^*$	0.11	0.09	0.07	0.04	0.03	0.03	0.20	0.09	-0.06

Sources: as described in previous tables.

Notes: The table displays medians of estimated crisis effects in three subperiods: (per1) the period between the first crisis year and the trough, the lowest real GDP growth period; (perF) the full crisis; and three-periods following the crisis (post). Effects are calculated by a difference-in-differences approach: the observed subperiod mean is compared to a counterfactual based on the pre-crisis mean and trends of the variable in control (normal repayer) countries. Bootstrap statistics are used due to small sample sizes. For variable definitions see notes in Table A.9. *: for crisis indicators, the mean crisis effects are reported instead of the median.

Table A.15 investigates the other question of how fundamentals are influenced by default/funding crisis spells. I chose a difference-in-differences approach here to control for common linear trends in some variables. The estimated effect on variables is calculated as the difference between the observed data and a counterfactual (what would the data have been were the country not to have defaulted), the latter which is based on the pre-spell period adding the mean changes of the variable in the control group (countries that were and remained normal repayers).⁷

On the upside, default spells and turning to the IMF appear to improve some of the macro imbalances seen in the pre-crisis states. Both default spell types result in lower debt dynamics post-spell, the ND spells also manage to reduce the debt ratio significantly in a statistical sense.

⁷I also tried a matching exercise to use only a group of the control countries with similar characteristics, but probably due to large numbers of missing observations nearest-neighbor searches often return bizarre matches, so instead I used the mean of all available countries that were normal repayers throughout the respective periods (from pre-spell to post-spell).

Figure A.10: Kernel densities of fundamentals in normal repayment and pre-crisis spells

Sources: author's compilation.

Notes: Each subplot in the figure shows ...

These debt reductions are however still very small compared to full debt writedowns assumed by many studies. Reserves increase and current account and fiscal balances improve in these spells.

The downside seems to be important: GDP per capita appears lower throughout and does not reach levels estimated where it would have ended up without a default. In the beginning of these spells growth is significantly reduced and all sorts of financial crisis probabilities increase. Debt levels rise shockingly during the spell (and remain higher post-spell without a default in a funding crisis). Political stability is lower after the spell.

Table A.15 supports a view that from the willingness to pay aspect a government would choose to default to regain macroeconomic stability even though this sacrifices income on the long-run. If the ability to fund itself from the market is lost, the government can turn to the IMF and choose repayment, which appears to result in smaller eventual income losses, but unfortunately the debt ratio and the external share of debt increases and political risks increase (ICRG rating decreases), all of which raises the chance of a subsequent default.

Again, kernel densities fitted to all spells in Figure A.10 caution that there are large differences across individual cases. It may well be that a government that chooses the default policy

believes that it will manage to record growth rates in the upper parts of the distribution of historical experiences either due to overoptimism or attention focusing (whether rightfully or wrongly) on some of the more benign experiences.

Appendix B: Proofs

B.1 Proofs of Chapter 5 results

B.1.1 Useful tools for proofs

For the proofs it is useful to state some lemmas and definitions first. The intuition of these are as follows. First (Lemma B.1), notice that the SDV derivative with respect to Z can be split into component partial derivatives of normal, crisis and long-term states (see equation 5.8). SDV is increasing in Z if for all these SDV constituents it can be shown that default A derivatives are larger than repayment A derivatives. (Vice versa for decreasing SDV). The easiest case is when derivatives of default terms and repayment term are of opposite sign, then monotonicity of the SDV component (the difference of default and repayment derivatives) already follows (Lemma B.2). When default and repayment terms are of the same sign calculation of SDV derivative sign is more complex. There a simple special case when derivatives of A terms in default and repayment are equal (Lemma B.3). For the more general case: it is useful to identify the minimum bounds of the default term derivative (Lemma B.4). To show that default term derivatives are larger than the repayment term derivative (hence SDV is increasing in the fundamental), it is sufficient to show that the minimum of the two default component derivatives is already larger than the repayment derivative (Lemma B.5).

Definition B.1. Define $SDVi$ as SDV in one of the three states: short-term normal state; short-term crisis state and long-term state.

Lemma B.1. (*SDVi aggregation*) SDV is a monotonically increasing function of fundamental Z , if in each of the three states: short-term normal state; short-term crisis state and long-term state $SDVi$ is monotonically increasing in Z .

Conversely, SDV is a monotonically decreasing function of fundamental Z state if in each of the three states: short-term normal state; short-term crisis state and long-term state $SDVi$ is monotonically decreasing in Z .

Proof. Because the overall SDV derivative with respect to the fundamental is a weighted sum of $SDVi$ derivatives in each state with positive weights (equation 5.8), SDV is decreasing if all component derivatives are decreasing. Conversely, when $SDVi$ is increasing in Z in each state, then SDV is also an increasing function of the fundamental. $\square$

Lemma B.2. (*Opposing signs of repayment - default derivatives*) $SDVi$ is a monotonically increasing function of fundamental Z if in that state $\partial A^R / \partial Z \leq 0$ and $\partial A_n^D / \partial Z \geq 0$ and $\partial A_c^D / \partial Z \geq 0$.

Conversely, $SDVi$ is a monotonically decreasing function of fundamental Z state if $\partial A^R/\partial Z \geq 0$ and $\partial A_n^D/\partial Z \leq 0$ and $\partial A_c^D/\partial Z \leq 0$ in that state.

Proof. In any state, when the derivative of repayment value is non-positive and the derivatives of default value are non-negative, then (due to value functions and probabilities being non-negative) the derivative of $SDVi$ is non-positive by equation (5.9) and so $SDVi$ in that state is increasing in the fundamental. Conversely, when default value derivatives are non-positive and the repayment value derivative is non-negative, then $SDVi$ is a decreasing function of the fundamental. $\square$

Remark B.1. In the short-term normal state $1/A_{Sn}^D \leq 1/A_{Sc}^D$ if $r \leq r_C$. In the short-term crisis state $1/A_{Sn}^D \leq 1/A_{Sc}^D$.

First, the distinction between the two default states ($s = n, c$) is only made in the short-term (crisis ends by the long-term). In the short-term, $A_{Nc}^D - A_{Nn}^D = -g_c/(1+\bar{g}) + HdP(R_C - R_N)$. Because $g_c, (1+\bar{g}), H, d, P > 0$ and $R_C - R_N = (r - r_C)/[(1+r)(1+r_C)] \leq 0$ when $r \leq r_C$ ($1+r, 1+r_C > 0$ is assumed), both terms in $A_{Nc}^D - A_{Nn}^D$ are non-positive. In the initial crisis state $A_{Cc}^D - A_{Cn}^D = -(g_c + g_C)/(1+\bar{g})$, which is non-positive as g_C is also positive. Thus $A_{Sc}^D \leq A_{Sn}^D$ for both states S when $r \leq r_C$ and is true in crisis without the latter inequality. Since $A_{Ss}^D > 0$ by model assumptions, the remark follows by inverting the terms.

Remark B.2. $\frac{1}{A_{Sn}^D} \leq (1 - \pi_c)\frac{1}{A_{Sn}^D} + \pi_c\frac{1}{A_{Sc}^D} \leq \frac{1}{A_{Sc}^D}$ in the crisis state. It holds in the normal state if $r \leq r_C$.

This remark is obtained from Remark B.1 and the fact that $(1 - \pi_c)/A_{Sn}^D + \pi_c/A_{Sc}^D$ is a convex combination of end points, $1/A_{Sc}^D$ and $1/A_{Sn}^D$.

Lemma B.3. (Equality of repayment - default derivatives) In the crisis state, $SDVi$ is a monotonically increasing function of fundamental Z if (i) $\partial A^R/\partial Z = \partial A_n^D/\partial Z = \partial A_c^D/\partial Z = \partial A/\partial Z \geq 0$ and (ii) $A_n^D \leq A^R$;

or if (iii) $\partial A^R/\partial Z = \partial A_n^D/\partial Z = \partial A_c^D/\partial Z = \partial A/\partial Z \leq 0$ and (iv) $A_c^D \geq A^R$.

Conversely, $SDVi$ is a monotonically decreasing function of fundamental Z if (i) and (iv); or if (iii) and (ii).

These conditions hold in the short-term normal state if $r \leq r_C$.

Proof. By model assumptions all A terms ($A_{Ss}^{R/D}$) are positive for all states. Using the equal partial derivatives of A , $\partial A/\partial Z$ in equation (5.9), in each (initial or long-term) state the SDV derivative is non-negative, when $\partial A/\partial Z \left([(1 - \pi_c)/(A_{Sn}^D) + \pi_c/(A_{Sc}^D)] - [1/A_{Sn}^R] \right) \geq 0$. When $\partial A/\partial Z \geq 0$, $(1 - \pi_c)/(A_{Sn}^D) + \pi_c/(A_{Sc}^D) \geq 1/A_{Sn}^D \geq 1/A_{Sn}^R$ is needed, where Remark B.2 is used to identify the lower bound for the left hand side of the inequality. Thus SDV is increasing in Z when $\partial A/\partial Z \geq 0$ and $A_{Sn}^D \leq A_{Sn}^R$. SDV is also increasing in Z when $\partial A/\partial Z \leq 0$ and $(1 - \pi_c)/(A_{Sn}^D) + \pi_c/(A_{Sc}^D) \leq 1/A_{Sc}^D \leq 1/A_{Sn}^R$, so $A_{Sc}^D \geq A_{Sn}^R$. This proves the first part of the lemma. The second part for the SDV decreasing in Z is analogous. $\square$

Definition B.2. Define $A_L^{D'}$, $A_U^{D'}$, w_L^D , w_U^D , W_L^D , W_U^D such that

$$\begin{aligned} A_L^{D'} &= \min(\partial A_n^D / \partial Z, \partial A_c^D / \partial Z), \\ A_U^{D'} &= \max(\partial A_n^D / \partial Z, \partial A_c^D / \partial Z), \\ w_L^D &= \min(1/A_n^D, 1/A_c^D), \\ w_U^D &= \max(1/A_n^D, 1/A_c^D), \\ W_L^D &= \min\{(\partial A_n^D / \partial Z) / A_n^D, (\partial A_c^D / \partial Z) / A_c^D\}, \\ W_U^D &= \max\{(\partial A_n^D / \partial Z) / A_n^D, (\partial A_c^D / \partial Z) / A_c^D\}, \end{aligned}$$

for a given initial state of nature N or C , or the long-term.

Lemma B.4. Given that W_c^D can be written as $W_c^D = (A_n^{D'} + x) / (A_n^D + xz + y)$, where x, y, z are real scalars, then:

if $x(A_n^D - A_n^{D'}z) - yA_n^D \geq 0$ then $W_c^D \geq W_n^D$, so that $W_L^D = W_n^D$ and $W_U^D = W_c^D$;
if $x(A_n^D - A_n^{D'}z) - yA_n^D \leq 0$ then $W_c^D \leq W_n^D$, so that $W_L^D = W_c^D$ and $W_U^D = W_n^D$.

Proof. For the lemma the sign of $W_c^D - W_n^D = (A_n^{D'} + x) / (A_n^D + xz + y) - A_n^{D'} / A_n^D$ is needed. The expression can be written as $[(A_n^{D'} + x)A_n^D - A_n^{D'}(A_n^D + xz + y)] / [(A_n^D + xz + y)A_n^D]$. The denominator of this term is positive by model assumptions so the sign is determined by the nominator. The denominator can be simplified to $x(A_n^D - A_n^{D'}z) - yA_n^D$. When this term is non-negative and $W_c^D \geq W_n^D$ and when it is non-positive $W_c^D \leq W_n^D$, which proves the lemma. $\square$

Definition B.3. Define $A^R = \partial A^R / \partial Z$, $w^R = 1/A^R$ and $W^R = A^R w^R$.

Definition B.4. Define $W^D = (1 - \pi_c^D)W_L^D + \pi_c^D W_U^D$, if $(\partial A_n^D / \partial Z) / A_n^D \leq (\partial A_c^D / \partial Z) / A_c^D$. Otherwise define $W^D = \pi_c^D W_L^D + (1 - \pi_c^D)W_U^D$.

Lemma B.5. (Using default derivative bounds) SDV is increasing in Z if $W^R \leq W_L^D$. Conversely it is decreasing when $W^R \geq W_U^D$.

Proof. First, note that bounds on W^D can be established as $W_L^D \leq W^D \leq W_U^D$ because probabilities are non-negative. Then, by equation 5.5 we can restate $\partial \text{SDV} / \partial Z$ more simply as $\partial \text{SDV} / \partial Z = W^D - W^R$. Lemma B.5 follows directly. $\square$

Lemma B.6. If the lower bound of the default derivative W_L^D can be written as $W_L^D = (A^R + x) / (A^R + xz + y)$ with x, y, z real scalars, then SDV is increasing in Z if $x(A^R - A^{R'}z) - yA^R \geq 0$. If the upper bound of the default derivative W_U^D can be written as $W_U^D = (A^R + x) / (A^R + xz + y)$, then SDV is decreasing in Z if $x(A^R - A^{R'}z) - yA^R \leq 0$.

Proof. The proof is analogous to Lemma B.4. For the lemma the sign of $W_j^D - W^R = [(A^R + x)A^R - A^{R'}(A^R + xy)] / [(A^R + xy)A^R]$ is needed. The denominator of this term is positive by model assumptions so the sign is determined by the nominator. This can be written $(A^R + x)A^R - A^{R'}(A^R + xy) = x(A^R - A^{R'}y)$. When this term is non-negative and $W_j^D = W_L^D$

then SDV is increasing in Z by Lemma B.5, which proves the first part. When this term is non-positive and $W_j^D = W_U^D$ by Lemma B.5 SDV is decreasing in Z , which proves the second part. $\square$

B.1.2 Proof of Propositions

Components of SDV derivatives with respect to various fundamentals are stated in Table 5.3. Further, bounds on various parameters are given in Table 5.1. Both are used extensively in the proofs below. An important (and standard) assumption (that is also used in lemmas stated above) is that utility function arguments (endowment corrected by net borrowing terms) are positive in all states of nature. Also, I use the following abbreviations in formulas: $H = 1 - h$, $P = (\psi + \alpha_1)/(1 + \bar{g})$, $R_N = (\bar{g} - r)/(1 + r)$, $R_C = (\bar{g} - r_C)/(1 + r_C)$.

Proof of Proposition 5.1. By the assumption of the proposition $r = r_C$. Then, A derivatives by $\bar{g}$ are given by $A^{R'} = dPR'$, $A_n^{D'} = dHPR'$, $A_c^{D'} = dPR'c'$, where $R' = 1/(1 + r)$ and $c' = g_c/(1 + \bar{g})^2$ in the normal state and has an additional $g_C/(1 + \bar{g})$ term in the crisis state. These derivatives are all positive and $A_c^D < A_n^D$, so $W_L^D = A_n^{D'}/A_n^D$ and $W_U^D = A_c^{D'}/A_c^D$. SDVi is decreasing in $\bar{g}$ if $0 \leq W^R - W_n^D$.

W_c^D can be written as $(A^{R'} + x)/(A^R + y)$, where $A^{R'} = dPR'$, $x = -hdPR' - c'$, $A^R = G_R + dPR$, $y = -hdPR - c$ and $c = g_c/(1 + \bar{g})$. Then using Lemma B.6 $W_c^D - W^R$ has the same sign as $A^R x - A^{R'} y$ (using $A^R, (A^R + y) > 0$). This expression is $dPR'(c + dPRh) - (G_R + PRd)(c' + dPR'h)$. Since $0 \leq G_R, P, R, d, c', R', h$ the first term of the expression is negative if $c < dPRh$ (as given in the proposition) and the second term is always positive, which shows that SDV decreases in $\bar{g}$ under these assumptions. $\square$

Proof of Proposition 5.2. SDVi derivatives by g_C are 0 for the initial normal and long-term states so SDVi derivatives in crisis determines the overall SDV derivative. In the crisis state, the derivatives of A are equal $(-1/(1 + \bar{g}))$ so Lemma B.3 can be used. Because derivatives of A are negative here, condition (iii) is true. Therefore, SDVi increases if $A^R \leq A_c^D$ and decreases if $A_n^D \leq A^R$.

The first condition is true if $0 \leq G_{Cc} + dHPR_C - (G_C + dPR_C) = -g_c/(1 + \bar{g}) - dhPR_C$. Rearranging and expanding, SDV increases in g_C if $g_c \leq h(\psi + \alpha_1)(r_C - \bar{g})/(1 + r_C)$ as stated in the proposition.

The second condition is true if $0 \leq G_C + dPR_C - (G_C + dHPR_C) = dhPR_C$. Using $d, h, (1 + \bar{g}), (1 + r_C) > 0$, SDV is decreasing in g_C if $0 \leq (\psi + \alpha_1)(\bar{g} - r_C)$, which is true by proposal assumptions. $\square$

Proof of Proposition 5.3. Derivatives of A terms are 0 for repayment and default without crisis and it is negative for default-induced crisis $(-1/(1 + \bar{g}))$ for ν_1 and $d(1 - \psi)h/(1 + \bar{g})$ for ν_2). For normal and crisis states, we can use Lemma B.2 to show that SDVi is decreasing in

the parameters, because the repayment derivative is non-negative and default derivative is non-positive. In the long-term the effect is zero, so overall SDV is decreasing in these parameters by Lemma B.1. $\square$

For the next two proofs a bit of algebra is needed upfront. By equation (5.7) and (5.8), SDVi of the long-term state has a weight $\beta^T/(1 - \beta)$, whereas the normal and crisis state SDVi components are multiplied by $(1 - \pi_C)(1 - \beta^T)/(1 - \beta)$ and $\pi_C(1 - \beta^T)/(1 - \beta)$ respectively. SDVi in the normal state differs from the long-term (denote as SDV_L) due to the default crisis endowment loss ($g_c/(1 + \bar{g})$ denote this by c in the proofs), which has probability of π_c . (It also depends on real interest rates increasing in crisis, but the assumption $r = r_C$ eliminates this factor). Denote the crisis state SDVi as SDV_C here. Then, SDV is:

$$\begin{aligned} SDV &= \frac{(1 - \pi_C)(1 - \beta^T)}{1 - \beta} (SDV_L(1 - \pi_c) + (SDV_L - c)\pi_c) + \\ &\quad \frac{(1 - \pi_C)(1 - \beta^T)}{1 - \beta} SDV_C + \frac{\beta^T}{1 - \beta} SDV_L = \\ &\quad \frac{1}{1 - \beta} \{SDV_L + (1 - \beta^T)[\pi_C(SDV_C - SDV_L + \pi_c c) - \pi_c c]\} \end{aligned} \quad (B.1)$$

Proof of Proposition 5.4. Using equation (B.1), which is valid if $r = r_C$, the derivative by T is $-\beta^T \log \beta [\pi_C(SDV_C - SDV_L + \pi_c c) - \pi_c c]$. The expression is non-negative if the term in brackets is positive, because $0 \leq -\beta^T \log \beta$. The assumptions $SDV_L \leq SDV_C$ and $c = 0$ in the first part of the proposition guarantees this (using $0 \leq \pi_C$). Therefore SDV is increasing in T as proposed. For the second part, the assumption $\pi_C = 0$ and $c > 0$ ensures that the term in brackets is negative, due to $0 \leq \pi_c$ and so SDV is decreasing in T , which completes the proof. $\square$

Proof of Proposition 5.5. Using equation (B.1), which is valid if $r = r_C$, the derivative of SDV with respect to β is:

$$\frac{\partial SDV}{\partial \beta} = \frac{SDV_L - \pi_c c + \beta^T \pi_c c}{(1 - \beta)^2} + \frac{T \beta^T \pi_c c}{\beta(1 - \beta)}$$

The expression can be split into two additive terms, one that includes SDV_L and one that does not.

The part with SDV_L is $SDV_L/(1 - \beta)^2$. Due to the assumption of repayment in the long-term ($SDV_L < 0$) and parameter assumptions for β and T , this term is negative.

Evaluating the other part is equivalent to evaluating the derivative with $SDV_L = 0$. Then:

$$\frac{\partial SDV}{\partial \beta} = \frac{\pi_c c [T \beta^T (1 - \beta) - \beta(1 - \beta^T)]}{\beta(1 - \beta)^2}$$

Because $0 < \pi_c c / [\beta(1 - \beta)^2]$ due to parameter assumptions, the proposition is proved if it can be shown that

$$S(T) = T\beta^T(1 - \beta) - \beta(1 - \beta^T) \leq 0, \quad T \in \{1, \dots, 100\}.$$

This is shown by induction.

For $T = 1$: $S(T) = 0$.

For $T + 1$ we can write:

$$S(T + 1) = (T + 1)\beta^{T+1}(1 - \beta) - \beta(1 - \beta^{T+1}) = S(T) - T\beta^T(1 - \beta)^2$$

By parameter assumptions $0 < T\beta^T(1 - \beta)^2$, so the expression S decreases as T increases. Since the first relevant element of the T sequence is shown to be non-positive, every element with T larger must also be negative. This shows that the part of the derivative independent of SDV_L is negative for all values of T .

SDV is a decreasing in β , because both parts of the SDV derivative with respect to β are negative.

This completes the proof. $\square$

Proof of Proposition 5.6. By the assumption of the proposition $r = r_C$. Then, A derivatives by r are given by dPR' , where $R' = -(1 + \bar{g})/(1 + r)^2$ for repayment and $dHPR'$ for both default terms in all three states. These derivatives are both negative and $A_c^D < A_n^D$, so $W_L^D = A_c^{D'}/A_c^D$ and $W_U^D = A_n^{D'}/A_n^D$. SDVi is increasing in r if $0 \leq W_c^D - W^R$ and decreasing in r if $0 \leq W^R - W_n^D$.

SDVi is increasing in r if $W_c^D - W^R$ is non-negative. W_c^D can be written as $(A^{R'} + x)/(A^R + y)$, where $A^{R'} = dPR'$, $x = -hdPR'$, $A^R = 1 + dPR$, $y = -hdPR - c$ where $c = g_c/(1 + \bar{g})$. Then using Lemma B.6 $W_c^D - W^R$ has the same sign as $A^R x - A^{R'} y$ (using $A^R, (A^R + y) > 0$). This expression simplifies to $dPR'(c - h)$. Since $0 \leq d, P$ and $R' \leq 0$ this expression is non-negative if $c \leq h$, which is assumed in the proposition. $\square$

Proof of Proposition 5.7. Derivatives of A terms are $A^{R'} = PR$, $A_n^{D'} = HPR$ and $A_c^{D'} = HPR - c'$, where $c' = \nu_2 h(1 - \psi)/(1 + \bar{g})$.

For the first part, when $R \leq 0$ ($r \geq \bar{g}$) then the derivatives are all negative since $0 \leq d, H, P$. $W_U^D = W_L^D = W_n^D$ because $\pi_c = 0$ is assumed. In this case SDVi increases if $0 \leq W_L^D - W^R$. Using Lemma B.6 with $A^{R'} = PR$, $x = -hPR$, $A^R = G_R + dPR$, $y = -hdPR$ with $G_R = 1$ in normal and long-term states and $G_R = G_C$ in crisis. The expression $A^R x - A^{R'} y$ simplifies to $-G_R PRh$, which is negative as all terms are positive except for R , which is negative. By Lemma B.6 SDV is increasing in d under these conditions.

In the second setting $R = 0$, so derivatives of A terms are 0 for repayment and default without crisis and it is negative for default-induced crisis ($0 \leq \nu_2, (1 - \psi), h, (1 + \bar{g})$). For normal and crisis states, we can use Lemma B.2 to show that SDVi is increasing in the parameters, because the repayment derivative is non-negative and the default derivative is non-positive. In the long-term the effect is zero, so overall SDV is decreasing in these parameters by Lemma B.1. $\square$

Implications: sign of effect of d depends on the role for default-induced crisis and R . A combination of low real rates and no perceived crisis costs causes SDV to be a decreasing function of ψ (higher external rate decreases default), however high crisis costs instead tend to increase the willingness to default.

Proof of Proposition 5.8. Derivatives of A terms are $A^{R'} = dR$, $A_n^{D'} = dHR$ and $A_c^{D'} = dHR + \nu_2 dh / (1 + \bar{g})$.

For the first part, derivatives of A terms are 0 for repayment and default without crisis and it is positive for default-induced crisis ($0 \leq \nu_2, d, h, (1 + \bar{g})$). For normal and crisis states, we can use Lemma B.2 to show that SDVi is increasing in the parameters, because the repayment derivative is non-positive and default derivative is non-negative. In the long-term the effect is zero, so overall SDV is increasing in these parameters by Lemma B.1.

For the second part, when $0 \leq R$ then the derivatives are positive and $W_L^D = W_n^D$ and $W_U^D = W_c^D$. SDVi decreases if $W_U^D - W^R \leq 0$. Using Lemma B.6 with $A^{R'} = dR$, $x = -hdR$, $A^R = G_R + dPR$, $y = -hdPR - c$ with $G_R = 1$ in normal and long-term states and $G_R = G_C$ in crisis and $c = g_c / (1 + \bar{g})$. The expression $A^R x - A^{R'} y$ simplifies to $dR(c - G_R h) = -hdRG_{C_c}$ where is the endowment in the default-induced crisis in either normal, crisis states and is equal to 1 in case of the long-term. The expression is negative, which shows SDV to be decreasing in ψ when $0 \leq R$ so $r \leq \bar{g}$. $\square$

Proof of Proposition 5.9. Derivatives of A terms are $A^{R'} = dR$ and $A^{D'} = dHR$ for both default terms and in each state.

When $R \leq 0$ then the derivatives are negative and $W_L^D = W_c^D$ and $W_U^D = W_n^D$ because $A_c^D \leq A_n^D$. SDVi increases if $0 \leq W_L^D - W^R$. We can use Lemma B.6 with $A^{R'} = dR$, $x = -hdR$, $A^R = G_R + dPR$, $y = -hdPR - c$ with $G_R = 1$ in normal and long-term states and $G_R = G_C$ in crisis and $c = g_c / (1 + \bar{g})$. The expression $A^R x - A^{R'} y$ simplifies to $dR(c - G_R h) = -hdRG_{C_c}$ where is the endowment in the default-induced crisis in either normal, crisis states and is equal to 1 in case of the long-term. The expression is non-negative since $0 \leq G_c, h, d$ and $R \leq 0$ in each state so that (by Lemma B.1) SDV is increasing in α_1 when $R \leq 0$ so $\bar{g} \leq r$.

When $0 \leq R$ then the derivatives are positive and $W_L^D = W_n^D$ and $W_U^D = W_c^D$. SDVi decreases if $W_U^D - W^R \leq 0$. We can use Lemma B.6 again with the same substitutions as above and $A^R x - A^{R'} y = -hdRG_c$ again. The expression is now negative, which shows SDV to be decreasing in α_1 when $0 \leq R$ so $r \leq \bar{g}$. $\square$

Appendix C: Miscellaneous

C.1 Fiscal policy model

This section presents a model of endogenous fiscal policymaking that shows sufficient conditions to prefer (i) operating a large public sector in the economy and (ii) preferring to bring forward public consumption using debt finance: i.e running up government debt.

The model is related to the vast literature strand that discusses the rationale for (domestic) debt finance of public spending. Barro (1974) argued that debt finance does not have an advantage over taxation under the permanent income hypothesis and this also implies a sceptical position on fiscal expansions under new classical assumptions (Molnár et al., 2017). Barro (1979) provided a rationale for debt finance due to tax smoothing, but this idea supports only low levels of public debt, moreover a government net asset position that fluctuates around zero. This is at odds with the empirical prevalence of high levels of public debt and deficit bias. Bounded rationality (consumer myopia and fiscal illusion) (Buchanan and Wagner, 1977) and political economy theories (Alesina and Tabellini, 1990, 2005) seemed to be better explanations. Another strand allows for large fiscal multipliers and deficit spending due to household heterogeneity regarding indebtedness and credit constraints and the zero lower bound of interest rates (e.g. Eggertsson and Krugman, 2012; Eggertsson and Mehrotra, 2014; Pragidis, Tsintzos and Plakandaras, 2017).⁸ Close to the current model are papers in the sovereign debt literature that envision domestic public debt as a tool for redistribution between bond investors and taxpayers at bond issuance and (in reverse direction) at subsequent debt servicing (Song, Storesletten and Zilibotti, 2012; D’Erasmus and Mendoza, 2016).

In order to have a parsimonious model and to be consistent with the main text (Chapter 5) I use the real endowment economy framework of the sovereign credit risk literature (Eaton and Gersovitz, 1981) augmented with public sector consumption as in endogenous fiscal policy models (e.g. Bohn, 1992). The model assumes a rational, utility maximizing government (no rent-seeking as in political economy models), but the government maximizes utility with respect to its voters, which is different than an aggregate social utility and adds a political economy element. In particular, the government maximizes utility with a larger focus on impatient households (low β) rather than patient investors (high β). The central ingredient of the model is thus household heterogeneity with respect to time preferences, which is also present in models of Eggertsson and Krugman (2012) and Pragidis, Tsintzos and Plakandaras (2017). Closest in this regard is D’Erasmus and Mendoza (2016), where the government differentiates between low- and high-wealth households and optimizes the relevant weighted utility based on its political platform.

⁸See further discussion in Chapter 2.

The current model takes a simpler, median voter approach and neglects aspects of partisanship. Households each have access to a resource $L = 1$ that can be used to produce private goods in the private sector and public goods in the public sector. There is no uncertainty in the model and there is common knowledge of the resource being available (and used at potential) in each period. Households take utility from consuming the two types of goods: private goods (denote by y_p the value of these) and public goods (value of y_g). Household savings are restricted to government bonds and takes a simple form of barter as detailed below. Following the classic sovereign credit risk literature, households are passive entities and their decisionmaking is not separately modelled. They consume all private and public goods produced proportionately and are indifferent about which sector they work for (in the public sector they are compensated by receiving the same amount of private goods that they would produce). They do not have leisure and use all resources in production.

Production of private goods is assumed to have linear technology and log utility. Denote by p the share of the resources devoted to this production. Then, utility of private sector goods is $y_p = \log(p)$.

The government operates the public sector by using the household resource endowment of magnitude g (this can be thought of as the share of households employed in the public sector). The value of public goods, evenly distributed among households, is also assumed to have log utility (positive and marginally decreasing) for households. The concrete functional form that I assume is $y_g = \vartheta \log g$.⁹ It can be shown that without tax distortions $g = \vartheta/(1 + \vartheta)$ is the optimal choice for the share of public sector resources, i.e. where the marginal utility of public and private goods production equal.¹⁰

There are two mechanisms for the government to obtain the resource g from households: by taxation and bond finance. Using either methods it can compensate households being employed in the public sector. Through taxation the government takes away a fraction τ of goods that the private sector produces. Keeping with the literature (Barro, 1979, and a vast literature since), taxation is assumed distortionary: it causes a utility (deadweight) loss.¹¹ I assume a quadratic

⁹I follow other papers that derive endogenous government policy (Bohn, 1992; Ambler and Paquet, 1996) in assuming a concave utility for public goods. Arguably, there are several indispensable functions of even a minimal state that are essential for the functioning of society and the private economy, but as the size of government grows the marginal utility of additional spending decreases. Here the model is more explicit about the relative value of private and public goods through the ϑ parameter: the marginal utility of public goods increases in this parameter, which results in higher share of resources allocated to the public sector in optimum. It is also plausible to think that (outside of extreme circumstances such as wars) this parameter is smaller than 1: if equal shares were allocated to private and public sector, spending on private goods would probably be valued more than additional spending on public goods.

¹⁰To see this denote τ the tax rate, then: $u = \log(1 - \tau) + \vartheta \log(\tau)$. The first-order condition is $1/(1 - \tau) = \vartheta/\tau$ leading to $\tau = \vartheta/(1 + \vartheta)$.

¹¹This can be thought of in one of several ways. A common line of thought is that the prospect of output being taxed causes agents in the private sector to choose more leisure time over work and hence production falls. Another possibility is tax evasion or misaligned incentives, which increase with the tax rate. Although this may still cause output to stay level, but evading taxes may still have disutility (e.g the fear of or the reality of punishment when getting caught). A third intuition for distortion may be due to heterogeneous labor preferences of households. As more household resources are allocated to the public sector, higher wages would need to be paid for new marginal

functional form for the loss. Specifically household private goods output are assumed to be reduced by $\delta\tau^2$ for a tax rate of τ . Consequently, tax collection and the associated deadweight loss together reduce the value of private output to $\log(1 - \tau - \delta\tau^2)$.

Other than taxation, the government can also issue bonds to finance expenditure. Bond finance involves receiving a share b of household private sector output in the given period from prospective bondholders (which can then be paid out to public sector employees). In exchange for these funds, the government returns $b(1 + r) = bR$ output next period, where r is the real yield, R is the yield plus notional on the bond. Bonds are auctioned to households in the private sector and I assume that households with higher subjective discount rates will be more inclined to participate. It is conventional to assume, and I will do so, that the real interest rate is determined endogenously by subjective discount rates: $R = 1/\beta_i$, where β_i is the discount rate of the marginal investor. Households with higher subjective discount rates are more relevant as investors on the government bond market, therefore their discount rates will exceed the median discount rate $\tilde{\beta}$.

The utility of households is viewed to directly and positively affect their voting, which is the key objective of the government aiming to remain in power. The government is assumed to follow median voter strategy and maximize the utility of the household with median characteristics, i.e. with $\tilde{\beta}$. Since $\tilde{\beta} < \beta_i$, $\tilde{\beta}R < 1$. Government will optimize utility for households that are more impatient than households that set conditions in the government bond market. An intuitive narrative could rely on the commonplace observation that wealth is concentrated in the hands of a small fraction of society (Mankiw, 2000) and that wealthy savers are more patient (have higher discount rates) (Harrison, Lau and Williams, 2002). Due to the small share of wealthy investors in the voting constituency, even conservative creditor-friendly parties would need to lean towards policies favoring impatient (middle-class) households. Admittedly, this argument sidesteps the potentially important reason why government may still consider bond issuance harmful: if government believes that (as theoretically plausible) bond finance reduces private investments and hence long-run growth. As reviewed in Chapter 2, however, empirical papers found mixed evidence on such a connection.¹²

households to be convinced to work in this sector.

¹²An empirical politico-economy strand (Alesina et al., 1998; Eslava, 2011; Brender and Drazen, 2008) provided empirical evidence that counters fiscal illusion and shows voters to be more fiscally conservative than conventional wisdom suggests even punishing governments that engage in deficit spending before elections. The validity of the empirical methods are however debatable due to potential reverse causality and that initial conditions may also influence results (see discussions by Barry Eichengreen and Maurice Obstfeld in Alesina et al., 1998, pp. 242-260). Also, these papers do not portray governments as being aware of such fiscal conservatism, quite on the contrary (e.g. Brender and Drazen, 2008, ends with the exclamation: "Politicians, take note!" suggesting that despite their empirical findings, the authors also view politicians as sticking with the conventional view). Thus (whether or not the electorate is fiscally conservative or displays fiscal illusion), the assumption that governments consider deficit finance to promote their electoral chances appears to be reasonable.

Tax only revenues

Consider an economy with no possibility of bond finance first. Formalizing the above model, household utility takes the form:

$$u = y_p + y_g = \log(1 - \tau - \delta\tau^2) + \vartheta \log(\tau),$$

using the budget constraint $g = \tau$. Parameter assumptions are $\tau \in [0, 1]$, and $\delta, \vartheta \geq 0$.

Without bonds and any other store of value households simply consume their endowment, though government chooses taxes to satisfy the maximum utility condition found at:

$$\vartheta = \frac{\tau(1 + 2\delta\tau)}{1 - \tau - \delta\tau^2}.$$

To bring some examples, when $\delta = 0.5$ and $\vartheta = 0.75$, utility is maximized at the tax rate of 0.34. At this tax rate 0.6 private goods are produced. Note that utility is negative as it sums the log of g and p , both smaller than 1, but are higher than the pure private sector economy and pure public sector economy both of which have utility of minus infinity.

The size of the optimal public sector decreases in the tax distortion parameter, δ , and increases in the relative value of public goods, ϑ . When $\delta = 1$ and $\vartheta = 0.1$ the optimal tax rate and public sector production is $g = 0.16$ and private sector resources are at $p = 0.82$. In contrast, when $\delta = 0.1$ and $\vartheta = 1.5$, so taxation is efficient and public goods are relatively valuable, then $g = 0.56$ and $p = 0.41$.

Bond and tax finance in a two-period economy

Consider now a two-period economy with issuance of a one-period government bond in the first period and no outstanding debt at that time. Initially the discount rate for second period utility is $\beta = 1$ and the real interest rate is 0, $R = 1$.

The objective function to solve in the first period is (already substituting the budget constraints $g_1 = \tau_1 + b$, $g_2 = \tau_2 - bR$):

$$\begin{aligned} \max_{\tau_1, \tau_2, b} \quad & u_1 + \beta u_2 = y_{p,1} + y_{g,1} + \beta(y_{p,2} + y_{g,2}), \\ & y_{p,1} = \log(1 - \tau_1 - \delta\tau_1^2 - b), \quad y_{g,1} = \vartheta \log(\tau_1 + b), \\ & y_{p,2} = \log(1 - \tau_2 - \delta\tau_2^2 + bR), \quad y_{g,2} = \vartheta \log(\tau_2 - bR), \end{aligned}$$

also subject to positivity (non-negativity) constraints $0 \leq \tau_{1,2}, b, g, \delta, \vartheta$ and $0 < y_{p,1,2}, 0 < y_{g,1,2}$. Solutions for the parameter choices of $\delta = 0.5$ and $\vartheta = 0.75$ and $\beta = 1$, $R = 1$ result in a balanced budget (no bond finance) in both periods with the same $\tau = 0.34$ tax rate in both periods that was found before. Taking government expenditure to be fixed yields a tax smoothing result. To see it more specifically, with the given δ, ϑ , and crucially the $R = \beta = 1$ parameters, the effect of a marginal increase in bond finance (reducing first period tax finance but increasing

it in the second) is:

$$\frac{\partial u}{\partial b} - \frac{\partial u}{\partial \tau_1} + \frac{\partial u}{\partial \tau_2} = \frac{t_1}{1 - \tau_1 - 0.5\tau_1^2 - b} - \frac{t_2}{1 - \tau_2 - 0.5\tau_2^2 + b},$$

which has a unique solution on the $[0, 1]$ interval of $b = 0$ and $\tau_1 = \tau_2$.

Lowering β (holding R fixed) promotes bond finance, although β has to be significantly reduced for bond finance to be material. With the same parameters, except $\beta = 0.1$, the effect of a marginal bond financed tax cut has the second term of the above expression multiplied by β , so if τ_1 and τ_2 were equal, the effect would be positive. An optimum would entail larger τ_2 , and thus bonds to be issued (in this example b is roughly 0.35). A parameter of $\beta = 0.8$ results in a debt ratio of 0.05 outstanding in the first period. The fact that only very low subjective discount rates result in material bond finance is due to the implausibly restricted behavior of government finances that requires government to repay all of its bonds outstanding without recourse to the bond markets. I relax this assumption next.

Bond and tax finance in the long run

Turning to a more realistic setting and one consistent with Section 5.1 government may now rollover its debt until a distant time period T . Also assume that (as before) the outstanding debt amount is chosen in the first period and repaid in the last period. For simplicity, in all interim periods the same level of debt (and tax rates) are assumed.¹³

The objective function is now:

$$\begin{aligned} \max_{\tau_1, \tau_2, b} u_1 + \sum_{t=1}^{T-1} \beta^t u_2 + \beta^T u_T &= y_{p,1} + y_{g,1} + \frac{\beta(1 - \beta^{T-1})}{1 - \beta} (y_{p,2} + y_{g,2}) + \beta^T (y_{p,T} + y_{g,T}), \\ y_{p,1} &= \log(1 - \tau_1 - \delta\tau_1^2 - b), & y_{g,1} &= \vartheta \log(\tau_1 + b), \\ y_{p,2} &= \log(1 - \tau_2 - \delta\tau_2^2 + b(R - 1)), & y_{g,2} &= \vartheta \log(\tau_2 - b(R - 1)), \\ y_{p,T} &= \log(1 - \tau_T - \delta\tau_T^2 + bR), & y_{g,T} &= \vartheta \log(\tau_T - bR), \end{aligned}$$

I will consider $T = 100$. When the discount rate is $\beta = 1$ and the real interest rate is 0, $R = 1$ there is no bond finance (taxes are set at the level in the tax only case). However, decreasing the discount rate just marginally to $\beta = 0.98$ already results in a large first period deficit, with $b = 0.35$ ($\tau_1 = 0.10$, $g_1 = 0.45$) and a last period surplus ($\tau_T = 0.6$, $g_T = 0.25$).

This points out that if the real interest rates and subjective discount factors are not perfectly aligned and the planning horizon of the government is long (the government does not intend to repay its debt for a long time), then Ricardian equivalence breaks down. Both of these as-

¹³This is restrictive and favors lower bond amounts in corner solutions, because government would plausibly afford higher debt ratios for most periods if it also had the option to repay over more periods at the end of the time horizon.

sumptions are likely to hold in reality. Even allowing the real interest rates to be set by marginal investors to the exact subjective discount rates as mainstream economic theory suggests, a small misalignment in the discount factor of the population relevant for government (i.e. voters in a democracy) and the discount rate of marginal investors is enough to promote government borrowing (as argued before voters are likely to have lower discount rates than the marginal investors). Regarding the plan of governments to be indebted on the long run it is enough to point out that there is a considerable supply of long maturity government bonds in both emerging and developed markets. Fiscal rules that set upper bounds to debt ratios significantly higher than zero suggest long-term calculation with government debt.

Table C.1 reports solutions for various parameter values.

Table C.1: Bond issuance and fiscal policy at various parameter values

INPUT PARAMETERS					SOLUTION OUTPUT								
β	R	T	δ	ϑ	b	period 1			period 2.. T			period T	
						τ_1	g_1	p_1	τ_2	g_2	p_2	τ_T	g_T
						Ricardian							
1.00	1.00	100.00	0.50	0.75	0.00	0.34	0.34	0.60	0.34	0.34	0.60	0.34	0.34
Political economy at varied discount rates													
0.90	1.01	100.00	0.50	0.75	0.39	0.03	0.42	0.58	0.34	0.34	1.00	0.64	0.25
0.95	1.01	100.00	0.50	0.75	0.34	0.07	0.41	0.59	0.34	0.34	0.95	0.60	0.26
0.99	1.01	100.00	0.50	0.75	0.01	0.33	0.34	0.61	0.34	0.34	0.61	0.35	0.34

Sources: author's compilation.

Notes: The table shows optimal taxation (τ) in the three types of periods and bond issuance (b) in the first period, which is rolled over until redemption in period T. Government uses taxes and bonds to finance public services g . The optimization depends on the discount rate β , gross real interest rate $R = 1 + r$, horizon of bond issuances government parameters: tax distortions δ and relative value of public goods ϑ .

Utility effect of net borrowing

From the point of view of Section 5.1 (Assumption 5.1) key questions are how an increase in debt service (due to for instance changing real interest rates or an exogenous increase in debt level) and new issuances affect utility given an initial debt level in any interim periods ($t \in \{2 \dots T - 1\}$) – at plausible values of δ and ϑ parameters. These are necessarily partial results, because in an optimum debt level will be set to satisfy the condition that a change in either direction would entail lower utility. However for any given period, the effect may either be positive or negative. Since the model in Section 5.1 is set up as additive discounted utility streams it is useful to look at individual period subutilities.

First, note that in interim periods taxes will be set to a level that equates the marginal utility of private goods and public goods:

$$\frac{\partial u_2}{\partial \tau_2} = \frac{-1 - \delta\tau_2}{1 - \tau_2 - \delta\tau_2^2 + br - \Delta b} + \frac{\vartheta}{\tau_2 - br + \Delta b},$$

and so,

$$\frac{1 + \delta\tau_2}{1 - \tau_2 - \delta\tau_2^2 + br - \Delta b} = \frac{\vartheta}{\tau_2 - br + \Delta b}. \quad (\text{C.1})$$

The partial derivative of the interim period utility with respect to the real interest rate (r) is:

$$\frac{\partial u_2}{\partial r} = \frac{b}{1 - \tau_2 - \delta\tau_2^2 + br - \Delta b} - \frac{b\vartheta}{\tau_2 - br + \Delta b}$$

Extracting b and substituting the last term from equation C.1:

$$\frac{\partial u_2}{\partial r} = \frac{b - b(1 + \delta\tau_2)}{1 - \tau_2 - \delta\tau_2^2 + br - \Delta b} = b \frac{-\delta\tau_2}{1 - \tau_2 - \delta\tau_2^2 + br - \Delta b}. \quad (\text{C.2})$$

Because $\delta\tau_2$ is positive due to the assumption of tax distortions and debt is positive, the partial derivative is negative: an increase in real interest rates increases debt service, which is associated with a decrease in utility. The effect increases in tax distortions and decreases in the share of resources allocated to the private sector (itself a function of both tax distortions and the relative value of public goods).

The intuition for this result is that an increase in debt servicing raises private sector utility (by $1/y_p$), however it decreases public sector utility more (by $(1 + \delta\tau_2)/y_p$).

Similar derivations lead to:

$$\frac{\partial u_2}{\partial \Delta b} = \frac{\delta\tau_2}{1 - \tau_2 - \delta\tau_2^2 + br - \Delta b}, \quad (\text{C.3})$$

so that new issuances (which lead to increased public spending and hence increase the primary fiscal deficit) are utility-enhancing.

Government debt may change exogenously, e.g a crisis could lead to foreign exchange rate depreciation and increased value of debt or contingent claims of the banking sector could be realized (bailouts) or, on the contrary, a debt default could reduce the debt stock. Utility effects in these cases depends on whether the real interest rate is positive or negative. Assuming constant debt, the partial derivative with respect to the debt stock is:

$$\frac{\partial u_2}{\partial b} = r \frac{-\delta\tau_2}{1 - \tau_2 - \delta\tau_2^2 + br}. \quad (\text{C.4})$$

Therefore, utility increases with the debt stock if real interest rates are negative and decreases with debt stock if real interest rates are positive. Taken together with previous results, utility decreases as br , the primary balance, increases.

This is a consequence of taxes being distortionary (and has nothing to do with heterogeneity

of time preferences). Because taxes are distortionary this decreases the share of public goods relative to private goods.¹⁴ Then, a unit increase in br , which has the same unit impact on private goods as a negative unit impact on public goods, are valued differently on the margin. Because there are less public goods in optimum (due to tax distortion), a unit loss here has a disutility that exceeds the utility gain of a unit increase in private goods.

There is one further remark to make. Because the primary balance br is likely to be small relative to total resources available for private goods, $1 - \tau_2 - \delta\tau_2^2 + br$, the effect of a unit increase on utility is approximately linear. This follows from the functional form assumed for utility. The result is robust to using other CRRA forms of utility: altering the risk aversion parameter only raises the denominator to the appropriate power. For larger curvature in the utility function, the negative effect of the primary balance will be larger, but the effect will be negative and approximately linear.

Conclusions of the model

In this model government spending on public goods is valuable to society. Even though public goods are valued less than private goods of the same quantity diminishing utility of private goods creates incentives for a (benevolent) government to spend on public goods. Taxation has distortion costs, which limits the size of the state. When the subjective discount rate of households is equal to the real interest rate, the government prefers tax finance over bond finance due to tax distortions.

However allowing long-term government indebtedness and the subjective discount rate of households to be even marginally lower than the real interest rate, results in the government choosing long-term indebtedness. In this case Ricardian equivalence does not hold, even though neither the government nor households are myopic, they have full information and are rational. Based on this model, the preference for bond finance (i) increases in the time horizon for terminal debt repayments, (ii) decreases as the discount rate and real interest rates increase, (iii) increases when public goods production becomes more attractive (a high marginal utility relative to private goods and low tax distortions).

The model also shows that the primary balance necessary to keep the debt ratio constant is inversely related to household utility: primary surpluses act to decrease, primary deficits act to increase utility. This implies that increasing government debt service results in a positive value to bondholders that is less than the value of lost public goods. The negative effect is approximately linear in the debt ratio and the real interest rate and the magnitude of the effect depends positively on tax distortions and the size of the public sector to the private sector.

The results hinge on several assumptions, however most of these are either fairly standard or are arguably plausible in reality. The assumption of possible long-term government indebtedness is empirically motivated and seems to be the reality for most governments worldwide. The

¹⁴Rearranging equation (C.1) we have $yg_2/yp_2 = \vartheta/(1 + \delta\tau_2)$.

assumption of real interest rates not converging to the (relevant) subjective discount rate has been proposed in other studies that considered heterogenous households and credit constraints for impatient spenders ([Eggertsson and Krugman, 2012](#); [Pragidis, Tsintzos and Plakandaras, 2017](#)).

The key assumption though is having a discount rate that is lower than the real interest rate. This can be argued on political economy grounds. Under most circumstances the voting constituency has a relatively small share of households that are wealthy savers. Wealthy savers set the interest rates in bond markets, but they are likely to exhibit higher discount rates than is common in the population. A government focused on the utility of a more representative household than bondholders will optimize with real interest rates and relevant discount rates misaligned and tilted towards impatience in time preferences. This supports results in governments running up debt and more so for governments that are more egalitarian.

C.2 Quantitative model

This section has two key objectives. First, it provides a robustness test of the results in Chapters 5 and 6 as it shows their validity in a quantitative model with endogenous interest rate determination and more stochastic and dynamic elements. Second, using the endogenous determination of interest rates in these models, it refines and studies aspects of funding liquidity defaults. The scope of the thesis does not allow an in-depth elaboration of this model and this is left for future work.

Model III developed in this chapter is built on the quantitative modelling framework that is used extensively in the current sovereign credit risk literature (landmark papers are [Aguiar and Gopinath, 2006](#); [Arellano, 2008](#)). These models assume a benevolent, rational government that maximizes household utility by issuing optimal debt amounts and choosing optimal default/repayment policy for domestic residents and investors that set bond prices knowing and taking into account of the government policy function. The government and investors also take into account the current and expected state of the economy. The economy is modelled in a Markovian discrete state space setting, where transitions between states occur both exogenously (usually, the output deviation from trend) and endogenously due to the policy choices of government (typically, the debt ratio and repayment/default policy). The solutions of these models lead to equilibria, (i) where government satisfies the household consumption utility optimum with its policy given the state and investor bond prices and (ii) where bond prices are also at the investor optimum given the state and government policy.

The deviations of Model III from the canonical models in the literature build on ideas and assumptions introduced in Chapter 5. As in Models I and II before, a distinction is made between domestically issued (assumed to be local currency) debt and debt issued internationally (assumed to be foreign currency). There are important implications of this distinction as discussed before. First, defaulting has larger output costs when debt is domestically issued. On the other hand, external net issuances have a larger positive impact on utility. These would motivate governments to issue externally. However, as developed in Model II, large external debt increases the chance of funding crises, because the central bank can only provide last resort funding up to its official reserves. These ideas are carried forward in the current model with the addition that when debt is in foreign currency, a currency crisis may also act to increase the debt ratio, another adverse consequence of foreign issuances.

Government optimization includes the two political economy elements in the utility function. One of these sets a preference for deficit bias. The other political economy element embodies a social preference regarding defaults or repayment.

The model in this chapter includes both a financial crisis state and a funding crisis state, which are different compared to versions in the previous chapter. The financial crisis state aims to grasp key features of currency and banking crises that has both an endowment loss aspect and an increase in the debt stock related to the dollarization of the economy (proxied by external

issuances) and the importance and vulnerability of the financial sector (due to bailouts).

The funding crisis state involves international creditor funding of the government instead of bond investors. It may materialize due to an exogenous liquidity shock, as in Model II, or due to government policy choice. The value of the funding crisis state relative to market contracting states reflects the two main motivations for turning to outside help: (i) international assistance replaces market funding with cheap official funding and (ii) currency crisis and the associated endowment loss is limited as IMF funds provide a backstop for the currency fall. However international assistance comes at the cost of austerity, i.e. a restriction that limits primary balances to make debt sustainable.

Further, the funding crisis state takes the government one step closer to a possible non-strategic default due to inadequate funding liquidity. A special function is introduced which combines the ability and willingness to pay aspects of defaulting in a theoretically consistent manner. The modelled approach respects the theoretical arguments that the willingness to pay aspect is dominant in cases when the value of default is (clearly) higher or lower than that of repayment. However, the model allows a role for the ability to pay aspect when there is uncertainty about the relative value of repayment.¹⁵ If it does not clearly exceed that of default, then there may be controversies within the government regarding the optimal policy choice and negotiations with foreign creditors could drag on, because in these cases there is a larger benefit of trying to get a better deal, which would convince more of the sceptics of the value of staying in the contract. I assume that this policy uncertainty raises the chance of pending negotiations leading to periods with intermittent lack of international funding, which could then open the way for liquidity shortfalls subject to the availability of central bank reserves and oncoming stochastic funding needs.¹⁶

In contrast to standard quantitative sovereign risk models, I continue to assume that governments are restricted in their choice of the primary fiscal balance to a range of values that is experienced in empirical data. Thus extreme arbitrary jumps in the debt ratio are ruled out.¹⁷ However, in

¹⁵In fact, all of the parameters that were relevant in terms of default studied in the previous chapter (real trend growth rate and long-term real interest rates, the probability of financial crises, the probability and depth of default-triggered crises, and even the preferences of voters regarding default) are difficult to precisely assess.

¹⁶These assumptions are motivated by the recurring observation in the Greek Troika negotiations that the Greek government was floating the possibility of not repaying and risking a disorderly default if the conditionality they received was too harsh. Negotiations often seemed to be concluded just in time to avert a default due to an acute lack of funding liquidity. For an outside viewer and as such, investors, the key risk was that if bad economic or fiscal data came online in these moments, then negotiations could fall through.

¹⁷Large positive primary balances are rare, because these would place a large burden on current consumption, which is politically unfeasible. Large positive net issuances are rare on the other hand, because these would signal complacency and hence the government would probably face higher financing costs both contemporarily and later on as well (as investors learn that government is of a 'bad' type). Ideally bounds on primary balances would drop out automatically from sovereign debt models, so that there would be no need to exogenously restrict primary balances into empirically observed ranges. However, the standard factor that would service such automatic bounds, the curvature of the utility function, is not capable of delivering those at plausible levels of the risk aversion coefficient. Perhaps the problem is missing political economy aspects, heterogeneity or investor memory, or a more general misspecification of the utility function. Exploring these factors and curing this problem is not in the scope of the thesis, but it is important to have empirically plausible debt ratio dynamics, so I choose to exogeneously set these bounds to empirical observations.

contrast to models in Chapters 5 and 6, the government can adjust its debt ratio within given bounds.

A drawback of the model in this chapter compared to other models in the literature is its much more stylized output dynamics. Whereas literature models have a finer state space grid for output and take into account its autoregressive dynamics, the model studied here remains in a coarse state space structure with a normal repayment state and a few types and depths of crisis. These reduced dynamics can only capture the largest (tail risk) output deviations. However, it is exactly expectations about these tail risk scenarios that are probably the crucial factors in forward-looking decisions regarding repayment/default and in deciding to turn to international assistance for funding. Finer growth dynamics estimated on historical observations may perhaps be more important in choosing new debt issuance, however these historical experiences may be less valuable in crises.¹⁸ On the other hand, the key benefit of this omission comes in terms of model solution speed.

On a more technical note, I use an algorithm that reduces runtime for finding the equilibrium government value function and policy compared to the solution method widely used in the literature. This algorithm relies on calculating the value function in one step using the Leontieff inverse of transition probabilities and the current utility instead of iterating the value function. When the matrix to invert is moderately sized, this procedure can significantly reduce runtime.

C.2.1 Model III assumptions (states)

The Model III also assumes a real endowment economy with identical domestic households (voters). Households in each period consume all their endowments without the possibility to save or borrow. The endowment has two sources, one deriving from domestic output and another from government net foreign borrowing. As in Models I and II in the main text, domestic output is exogenously given with respect to states of nature and (repayment/default) policy. Net foreign borrowing is the choice of the government, but it is subject to constraints. These constraints are dependent on the given states of nature and policy denoted by S .

There are altogether seven states of nature and policy S in Model III:

NR Normal Repayment. The endowment is high, the government has market access and honors its obligations.

FR Financial Crisis and Repayment. Lower endowment than in NR due to a currency and/or banking crisis. The government has market access and honors its obligations. Currency depreciation and bank bailouts could increase the debt ratio.

CR Funding Crisis Repayment. The government honors its obligations, but depends on international assistance for funding as market access is lost. The endowment has output loss

¹⁸For instance, in all severe crisis cases there is considerable doubt about whether mean reversion to previous trend is to be expected at all. More generally, the relevance of historical dynamics in these cases are less obvious and therefore may service less information on decisionmaking as in normal times.

elements of the financial crisis but is less adverse.

NDn, NDc Normal Default: The government is in bad credit standing, excluded from markets, as a result of repudiating debt payments from state NR or FR. The endowment is reduced in both cases due to losses on domestic government bonds, but the endowment suffers further losses in NDc and entails elements of a currency crisis.

CDn, CDc Funding Crisis Default. The government is in bad credit standing, having defaulted on bonds from the CR state. These states are similar to NDn and NDc, but the exchange rate shock is more adverse.

These states combine elements of Model I and II, but there are several important differences. First, the output losses due to market valuation on bonds are endogenously related to credit risk as credit risk is taken into account by bond investors as later detailed. This way, output losses related to such valuation losses are high in default states when credit losses become certain, but lower in repayment states when default has lower probability.

Second, crisis states (each of the above states except NR and NDn) involve the possibility of debt ratio increases due to currency depreciation. Further, the FR state also involves additional stochastic jumps related to bank bailouts.

Third, entering the CR state may be realized both due to endogenous policy choice and exogenous liquidity shocks. When the sovereign faces large currency depreciation or high market bond spreads, and the value of the CR state exceeds that of NR or FR, then it makes sense for the government to choose to go to the IMF for help effectively excluding itself from the market. Finally, in the CR state a non-strategic default occurs only when there is an inherent uncertainty in policy decisionmaking in contrast to Model II, which also included a fixed probability of a liquidity induced disorderly default irrespective of the strategic default choice. Here, it is assumed that given a clear difference between the value of repayment and default, there is no role for the inability to pay aspect and the sovereign decides to repay based on its willingness, the strategic choice.

C.2.2 Model III assumptions (dynamics)

Figure C.11 shows the sequence of events within each time period.

In the beginning of the period, shocks of nature are realized related to the state and the debt ratio. These shocks are in the information set of both investors and government when they decide on their policies. The government decides on whether to default (ND,CD), turn to international assistance (CR) or repay and reissue new debt with primary balance pb_t (NR,FR,CR) given the bond price schedule (q_t), the current state (i.e. after subperiod t^-) and expectations of future utility given the decision. The investor bond pricing is simpler in that expectations for only one period need to be taken into account: namely, the next period initial natural state shocks and the subsequent government decisionmaking about default or repayment. Subsequent to the

Figure C.11: Sequence of events

Sources: author's compilation.

government decision, but still within period t , nature shocks may cause transition from the CR state to the CD state. Further, if there is an entry into default within the period, nature decides whether the benign (NDn, CDn) or adverse (NDc, CDc) sovereign crisis state materializes. These events and decisions are developed more formally below.

State dynamics

As seen in Figure C.11, determination of the state within each period is the result of (i) initial exogenous (nature) shocks preceding the policy decision, (ii) the government policy decision, and (iii) exogenous (nature) shocks after the policy decision.

The initial nature shocks to the state (i) determine moving into a financial crisis and out of financial or sovereign crises. Transition into the FR state occurs when p_{t-}^F , a Bernoulli distributed shock with probability π^F , takes a value of one. Similarly, crises FR, CR and market exclusion in ND and CD end when $p_{t-}^T = 1$, where probability $p_{t-}^T \sim \text{Bernoulli}(1/T)$. (This assumption results in the average crisis/exclusion duration of T periods).

A funding liquidity shock is assumed to be realized when $p_{t-}^{\lambda^l} = 1$, $p_{t-}^{\lambda^l} \sim \text{Bernoulli}(\lambda^l)$, which causes the transition from NR and FR to the CR state. Finally, non-strategic default occurs when $p_{t-}^{\lambda^a} = 0$, $p_{t-}^{\lambda^a} \sim \text{Bernoulli}(\lambda^a)$, which moves the state from CR to CD. If these binary shocks take a value of zero, then the state does not change. The transition matrix TR^{S-} presents state

transition probabilities due to the initial shocks (i).

There are two policy decisions in (ii) regarding the state. First, when the initial state is NR or FR, the government can decide to turn to international assistance (transition into the CR state). This is also a binary choice and I write it probabilistically, since its realization may involve uncertainty: when $p_t^C = 1$, which occurs with probability π^C , the CR state is realized, otherwise the status quo remains.

Second, given either of the repayment initial states (NR, FR, CR), the government can decide to default. Again, this may entail uncertainty, so that default is written as occurring (transition from NR, FR to ND and CR to CD) when $p_t^{\lambda^g} = 1$, which has probability λ^g . If $p_t^{\lambda^g} = 0$ the government decides to repay its maturing debt stock and to reissue debt at the same time.¹⁹

$$\begin{aligned}
 & \begin{array}{c} \text{from/to} \end{array} \quad \begin{array}{ccccccc} NR & FR & CR & NDn & NDc & CDn & CDc \end{array} \\
 & \begin{array}{c} NR \\ FR \\ CR \\ NDn \\ NDc \\ CDn \\ CDc \end{array} = TR^{S-} = \begin{pmatrix} \pi_{NRR} & \pi^F(1 - \lambda^l) & \lambda^l & 0 & 0 & 0 & 0 \\ \frac{1}{T}(1 - \lambda^l) & \pi_{nT}(1 - \lambda^l) & \lambda^l & 0 & 0 & 0 & 0 \\ \frac{1}{T}(1 - \lambda^a) & 0 & \pi_{nT}(1 - \lambda^a) & 0 & 0 & \lambda^a(1 - \pi_c) & \lambda^a\pi_c \\ \frac{1}{T} & 0 & 0 & \pi_{nT} & 0 & 0 & 0 \\ \frac{1}{T} & 0 & 0 & 0 & \pi_{nT} & 0 & 0 \\ \frac{1}{T} & 0 & 0 & 0 & 0 & \pi_{nT} & 0 \\ \frac{1}{T} & 0 & 0 & 0 & 0 & 0 & \pi_{nT} \end{pmatrix} \\
 & \pi_{nT} = 1 - \frac{1}{T} \\
 & \pi_{NRR} = (1 - \pi^F)(1 - \lambda^l)
 \end{aligned} \tag{C.5}$$

Finally, there are exogenous Bernoulli-distributed shocks after the policy decision (iii), which still influence the same period state. As in Chapter 5 and 6 models, defaulting can result in either a benign n or an adverse c scenario. When $p_t^c = 1$, the adverse state is realized, otherwise the benign state. In both ND and CD defaults $p_t^c \sim \text{Bernoulli}(\pi_c)$. TR^{S+} combines policy and state shocks to represent transition probabilities of (ii) and (iii).

¹⁹Model III has a structure with ND states having higher expected utility than CD states. Therefore CD is never chosen from NR or FR. CD is therefore either realized in the beginning of the period natural shock from CR, accidentally, due to a liquidity default or when, during the course of a CR spell, conditions change to make a default preferable.

$$\begin{aligned}
& \begin{array}{c} \text{from/to} \end{array} \begin{array}{cccccc} NR & FR & CR & NDn & NDc & CDn & CDc \end{array} \\
& \begin{array}{c} NR \\ NR \\ CR \\ NDn \\ NDc \\ CDn \\ CDc \end{array} = \begin{array}{c} \left(\begin{array}{cccccc} \pi_{RR} & 0 & 0 & \pi_{NRDn} & \pi_{NRDc} & 0 & 0 \\ 0 & \pi_{RR} & 0 & \pi_{NRDn} & \pi_{NRDc} & 0 & 0 \\ 0 & 0 & 1 - \lambda^g & 0 & 0 & \pi_{CRDn} & \pi_{CRDc} \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{array} \right) \end{array} \\
& \pi_{RR} = (1 - \pi_C)(1 - \lambda^g) \\
& \pi_{NRDn} = (1 - \pi_C)\lambda^g(1 - \pi_c) \\
& \pi_{NRDc} = (1 - \pi_C)\lambda^g\pi_c \\
& \pi_{CRDn} = \lambda^g(1 - \pi_c) \\
& \pi_{CRDc} = \lambda^g\pi_c
\end{aligned} \tag{C.6}$$

Endowment

The endowment assumptions are similar to those in Model I and II. Potential real endowment, $\tilde{Y}$ is assumed to grow at a constant trend rate of $\bar{g}$. Different states involve different temporary deviations from this potential output path. A new element introduced here is σ_y , which is a scale of output gap deviations.

$$\begin{aligned}
Y_t^S &= \tilde{Y}_t^S \frac{1 + \bar{g} - g^S}{1 + \bar{g}} \\
g^S &= \begin{cases} 0, & \text{if } S_{t-} = NR, \\ \nu_1/2 + g_{c2}/2 + g_{c3}, & \text{if } S_{t-} = FR, \\ \nu_1/2 + g_{c2}/2 + g_{c3}/2, & \text{if } S_{t-} = CR, \\ g_{c2}/2, & \text{if } S_{t-} = NDn, \\ \nu_1 + g_{c2} + g_{c3}, & \text{if } S_{t-} = NDc, \\ g_{c2}/2 + g_{c3}/2, & \text{if } S_{t-} = CDn, \\ \nu_1 + g_{c2} + g_{c3}, & \text{if } S_{t-} = CDc, \end{cases} \\
g_{c2} &= \nu_2 d(1 - \psi)(1 - q) \\
g_{c3} &= 2\nu_2\nu_3\psi
\end{aligned} \tag{C.7}$$

Debt ratio dynamics

The debt ratio is assumed to be affected by three types of events.

In the beginning of the period, the debt is reduced by the size of debt relief $\Delta d^h = dh^g$ if there is an exit from a default state. Also in this subperiod, t^- , in every state other than NR and NDn , the debt ratio is subject to a positive jump of size Δd^{sd} . This occurs with probability π^{sd} .

The size of debt ratio jumps depends on the state. The FR state assumes a banking crisis and the debt ratio potentially increases due to government recapitalization of troubled banks. This is assumed to be related to the size and vulnerability of the banking sector, which is captured by the parameter, ν_2 . If the economy is dollarized (proxied by a higher ψ) and there is a larger currency depreciation (proxied by higher ν_3), then the bailout is also assumed to be larger. The baseline parametrization results in an increase of the debt ratio by 9 percentage points, and when all involved parameters are at the maximum, the debt ratio jumps 23 percentage points.

A possible currency crisis inflates the foreign currency component of government debt, therefore this effect is related to $d\psi$ and the magnitude of depreciation, ν_3 . This component of debt ratio shocks are assumed to be larger in FR , NDc and CDc states, and milder in CR and CDn , where international assistance may cushion the exchange rate fall. At the baseline parametrization of 50 percent debt and 30 percent FX share, the increase adds 4 percentage points to the debt ratio. Maximum allowed debt levels and foreign currency share would instead add 28 percentage points.

These assumptions are summarized in (C.8).

$$\begin{aligned}
 d_{t^-} &= d_{t-1} - \Delta d^h + p_{t^-}^{sd} \Delta d^{sd} & p_{t^-}^{sd} &\sim \text{Bernoulli}(\pi^{sd}) \\
 \Delta d^h &= dh^g & \text{if } S_{t-1} \in \{ND, CD\} \text{ \& } S_{t^-} = NR, \\
 \Delta d^{sd} &= \begin{cases} \Delta d^{BANK} + \Delta d^{FX}, & \text{if } S_{t^-} = FR, \\ \Delta d^{FX}/2, & \text{if } S_{t^-} = CR, \\ \Delta d^{FX}, & \text{if } S_{t^-} = NDc, \\ \Delta d^{FX}/2, & \text{if } S_{t^-} = CDn, \\ \Delta d^{FX}, & \text{if } S_{t^-} = CDc, \end{cases} \\
 \Delta d^{BANK} &= 0.5\nu_2(1 + \nu_3\psi), \\
 \Delta d^{FX} &= 0.5\nu_3d\psi,
 \end{aligned} \tag{C.8}$$

If the government enters the t subperiod in the NR , FR or CR state, it decides on its debt issuance and debt repayment policy. If repayment is chosen, then in the NR and FR states, the government is assumed to be restricted in its choice of the structural primary balance in the -10 and +5 percent range, which is close to empirical 5 and 95 percentiles.

If the government is in the CR state, however, the primary balance has a lower bound that varies with its difference to an IMF target, d^{imf} . At the baseline parametrization, this value is assumed

to be 60 percent. When the debt ratio increases toward this limit, the government is allowed smaller primary deficits. When this limit is passed, only balanced budgets are allowed, whereas near the maximum considered debt levels the maximum considered surplus is required. These fiscal rules serve as the conditionality to international assistance and are intended to ensure sustainable debt ratios.

As derived in Chapter 5, a balanced primary budget and stable debt ratio is consistent with gross issuance of $d_{t-1}(1 + \bar{g})q_t$ according to the new output level (adjusting for trend growth of output) and at q_t (zero-coupon) bond prices. Maturing debt amounts to d_{t-1} .

$$\begin{aligned}
 nb_t &= d_{t-}[(1 + \bar{g})q_t - 1] - pb_t(1 + \bar{g}) \\
 d_t &= d_{t-} - pb_t \quad pb_L^S \leq pb_t \leq 0.05 \\
 pb_L^S &= \begin{cases} pb_L^S = -0.1, & \text{if } S_t = NR, FR, \\ pb_L^S = -0.1 + 0.05 \frac{d}{d^{imf}}, & \text{if } S_t = CR \text{ \& } d < d^{imf}, \\ pb_L^S = 0.05 \frac{d - d^{imf}}{d^{max} - d^{imf}}, & \text{if } S_t = CR \text{ \& } d \geq d^{imf}, \end{cases}
 \end{aligned} \tag{C.9}$$

In default states, the primary balance is assumed to be zero.

Full period S - d dynamics

Denote the state vector Sd the Kronecker product of S , d , where the states S are defined as above and d is a vector of debt ratio values in an allowed set $d \in \{d_{min} \dots d_{max}\}$.

There are three transition matrices of interest in later derivations.

First, the transition matrix in subperiod t^- , TR_{t-}^{Sd-} , entails the transitions of the state S from the end of the last period, i.e. $t - 1^+$ to the end of the subperiod t^- as defined by equation (C.5) and debt ratio transitions by equation (C.8). These transitions are mainly characterized by shocks of nature and fixed parameters of the economy.

Second, the transition matrix in subperiod, t and t^+ , TR^{Sd+} entails the transitions of the state S from the end of t^- to the end of t^+ as defined by equation (C.6) and debt ratio transitions in equation (C.9). These transitions are mainly characterized by shocks of government policy and fixed parameters of the economy.

Third, the full period transition matrix TR^{Sd} defines the transition probabilities of the state S and d from the end of $t - 1^+$ to the state outstanding at the end of t^+ . Formally these transition matrices satisfy:

$$\begin{aligned}
 Sd_{t+} &= TR^{Sd+} Sd_{t-}, & Sd_{t-} &= TR^{Sd-} Sd_{t-1+}, \\
 Sd_{t+} &= TR^{Sd} Sd_{t-1+}, & TR^{Sd} &= TR^{Sd+} TR^{Sd-}.
 \end{aligned} \tag{C.10}$$

Ability vs willingness aspects of default

The model formally separates the non-strategic (ability), λ^a , and strategic (willingness), λ^g , components of defaults. As seen in the state transition matrices (C.5) and (C.6), the non-strategic jump to default is realized in subperiod t^- , whereas the policy is decided in t . In the NR, FR states only strategic defaults are assumed to occur. In the CR state, defaults in each period are characterized by a compound probability, λ^C , that exceeds the strategic default probability λ^g by λ^a .

There are two key ingredients of government inability to service debt. First, uncertainty about the strategic aspect of default, e.g. $0 \ll \lambda^g \ll 1$, is needed, because when the government clearly prefers a default it cannot be stopped from doing so and when it clearly prefers repayment then it will comply with international creditor conditionality, who will in exchange cover any funding needs.

Second, the inability to pay is ultimately triggered by liquidity shortfalls. A government that does not have expiring debt or one that only has domestic currency debt with the ability to use central bank assistance to fund itself does not default non-strategically. This oncoming funding shortage is modelled with the same function as the exogenous liquidity shock was in Model II:

$$\lambda^l = \frac{1}{1 + \exp(-c_0 - c_1(d\psi - res))}, \quad (\text{C.11})$$

where $d\psi - res$ is the foreign-currency funding need not covered by reserves with c_1 scaling parameter and c_0 constitutes other factors influencing liquidity needs not captured by these fundamentals.

The compound default probability is assumed to take the form:

$$\begin{aligned} \lambda^C &= (1 - \lambda^l)\lambda^g + \lambda^l(\lambda^g)^z, \\ 0 &\leq z \leq 1, \end{aligned} \quad (\text{C.12})$$

where z is a parameter that sets the relative sensitivity of λ^C to λ^l .

Proposition C.1. *(Compound default probability)*

Assuming the relationship between λ^C , λ^l and λ^g in (C.12) the following properties characterize the compound default probability, λ^C :

- **Probability measure:** λ^C is in the $[0,1]$ range.
- **Monotonicity:** λ^C is increasing in both λ^l and λ^g .
- **No gunboat diplomacy:** If $\lambda^g = 1$, then $\lambda^C = 1$.
- **Repayment always a possibility:** If $\lambda^g = 0$, then $\lambda^C = 0$.
- **Strategic decision without liquidity problems:** If $\lambda^l = 0$, then $\lambda^C = \lambda^g$.

Proof. Simple algebra. □

These properties ensure a default process that is consistent with the two ingredients above.

Obviously one expects compound probability not to decrease when either the strategic default probability or liquidity shortfalls increase and equation (C.11) ensures this. As argued before, at the extremes of λ^g , it should determine λ^C . When government intends to default with certainty, $\lambda^g = 1$, it is to default (there is no gunboat diplomacy) and if it wants to certainly repay, $\lambda^g = 0$, it will find the means.²⁰ When there is no liquidity problem, $\lambda^l = 0$, then again λ^g determines λ^C .

The parameter z sets the sensitivity of λ^C to λ^l in all non-corner cases. The following corollary claims λ^C at the two extremes of z .

Corollary C.1. (Compound default probability: special cases)

(1) Strategic case: If $z = 1$, $\lambda^C = \lambda^g$.

(2) Symmetric case: When $z = 0$, $\lambda^C = \lambda^g + \lambda^l - \lambda^l \lambda^g$.

The $z = 1$ case encompasses the assumption of the theoretical sovereign debt literature, that posits only the strategic aspect is material in sovereign risk. In this case $\lambda^C = (1 - \lambda^l)\lambda^g + \lambda^l(\lambda^g)$, and the right-hand side simplifies to λ^g .

The $z = 0$ case instead leads to symmetric effects of the liquidity and willingness to pay components of default probability. In this case equation (C.11) is $\lambda^C = (1 - \lambda^l)\lambda^g + \lambda^l$, which is $\lambda^g + \lambda^l - \lambda^l \lambda^g$. Marginal increases in λ^g have an effect of $1 - \lambda^l$ on the overall default probability, and λ^l marginal increase has a $1 - \lambda^g$ effect.

C.2.3 Model III assumptions (Government optimization)

The government chooses the policy schedule $\Theta_{t \dots \infty}^g = \{\lambda_{t \dots \infty}^g, \pi_{t \dots \infty}^C, p b_{t \dots \infty}\}$ within their allowed sets (denote this by Θ^G) that maximizes its expected discounted utility given information available at t^- :

$$\begin{aligned} \max_{\Theta_{t \dots \infty}^g} E_{t^-} \left[\sum_{s=0}^{\infty} \beta^s u_{t+s} | I_{t^-} \right], \\ \text{s.t.} \quad \Theta_{t \dots \infty}^g \in \Theta^G \end{aligned} \quad (\text{C.13})$$

The information set, I_{t^-} , available at the period, t^- , collects (i) the state $S d_{t^-}$ i.e the states S and the outstanding debt ratio, (ii) the investor price schedule $q_{t^-} = q(S_t^-, d_t^- q)$ and (iii) a set of other parameters Θ_t^o that characterize the economy.

Utility in each period is given by

$$u_t = \log(y_t + n b_t(\psi + \alpha_1)) + \alpha_2 \mathbf{1}_{S_t \in \{ND, CD\}} \frac{\lambda_t^g}{\lambda_t^C}. \quad (\text{C.14})$$

²⁰This latter condition means that there should be no value of λ^l for which $\lambda^C > 0$ if $\lambda^g = 0$. This rules out several simpler functional forms, such as...

The utility has a household consumption utility element, the endowment and net foreign capital inflows ($y_t + nb_t\psi$), that constitutes the standard utility in the literature. Additionally, as discussed in Chapter 5 in detail, it has the political economy elements of the added preference for net borrowing $nb_t\alpha_1$ and debt repudiation α_2 . The latter term is corrected by a factor $0 \leq \lambda^g/\lambda^C \leq 1$, because government cannot claim to have increased voter utility in a default that was due to the ability to pay, i.e. $\lambda^C - \lambda^g$, rather than the government strategic decision. The logic of derivations in the literature regarding the value function of government policy is splitting the value function for repayment (which maximizes repayment utility choosing debt issuance) and default; and choosing the maximum of the two in the repayment-default decision step

Following this logic, in this model the value functions could be written out for repayment states NR, FR, CR and default states, and subsequently the choice between NR and CR; FR and CR; NR and ND; FR and ND; CR and CD could be evaluated to find the appropriate state transitions. To combine the two steps, we could more simply write value functions for the initial states with policy parameters λ^g and π^C (the choice of default and going to international assistance) already included.

In the NR state given debt ratio as at the end of the t^- subperiod, d_{t-} , the value function can thus be recursively written as:

$$\begin{aligned}
 V^{NR, d_{t-}} = & \max_{pb, \lambda^g, \pi^C \in \Theta^G} (u^{NR}(pb, \Theta, q) + \\
 & \beta[(1 - \pi^C)(1 - \lambda^g) \sum_{Sd_{t+1-}} p(\{NR, d\}, Sd_{t+1-}) V^{Sd_{t+1-}} + \\
 & \pi^C(1 - \lambda^g) \sum_{Sd_{t+1-}} p(\{CR, d\}, Sd_{t+1-}) V^{Sd_{t+1-}} + \\
 & \lambda^g(1 - \pi^C) \sum_{Sd_{t+1-}} p(\{NDn, d\}, Sd_{t+1-}) V^{Sd_{t+1-}} + \\
 & \lambda^g\pi^C \sum_{Sd_{t+1-}} p(\{NDc, d\}, Sd_{t+1-}) V^{Sd_{t+1-}}]). \tag{C.15}
 \end{aligned}$$

The first element is utility influenced by the choice of pb and latter elements are expected values of staying in the NR state or switching to either CR or default, i.e NDn or NDc, which are influenced by λ^g and π^C . Within each of those choices is a probability-weighted sum of state Sd transitions in the beginning of the next period (e.g. defaulters regaining market access with lower debt, normal repayers switching to liquidity crisis, repayers experiencing an ability to pay default and jumps in the debt ratio as explained at the beginning of the chapter).

The FR state is analogous.

The CR state has a somewhat simpler formulation as there is no government choice of π^C here:

$$\begin{aligned}
V^{CR,d_t-} = & \max_{pb, \lambda^g, \pi^c \in \Theta^G} (u^{CR}(pb, \Theta, q) + \\
& \beta((1 - \lambda^g) \sum_{Sd_{t+1}-} p(\{CR, d\}, Sd_{t+1-}) V^{Sd_{t+1}-} + \\
& \lambda^g(1 - \pi^c) \sum_{Sd_{t+1}-} p(\{CDn, d\}, Sd_{t+1-}) V^{Sd_{t+1}-} + \\
& \lambda^g \pi^c \sum_{Sd_{t+1}-} p(\{CDc, d\}, Sd_{t+1-}) V^{Sd_{t+1}-})). \tag{C.16}
\end{aligned}$$

The default state, as in the literature does not involve government decisions, the value function here reflects exogenous default endowments (no net borrowing) collecting α_2 until market access is regained. The value in the default state, NDn is:

$$V^{NDn,d_t-} = (u^{NDn}(\Theta) + \beta \sum_{Sd_{t+1}-} p(\{NDn, d\}, Sd_{t+1-}) V^{Sd_{t+1}-})). \tag{C.17}$$

Other default states are analogous.

C.2.4 Model III assumptions (Investor optimization)

Investors take into account that their bond investments q return 1 if the government repays and $1 - loss$ if it defaults. In a default the investors may be stuck with the position until renegotiations are concluded and even if they would receive the full notional this would need to be discounted at their subjective discount factors. Overall, losses are assumed to be valued at h^m , which are related to, but need not be equivalent to expectations of h^g , the debt relief.

Default is expected to occur according to the government policy of λ^g as well as probability λ^a , a liquidity default. The risk in holding bonds is due to stochastic shocks in the beginning of the next period, that may change the repayer state of government at issuance to a state where government rather chooses default. The probabilities of these transitions are in TR^{Sd-} .

Investors are therefore assumed to price bonds according to:

$$q_t(S_t, d_t) = \frac{1 - E_t[\lambda_{t+1}^C] h^m}{1 + r^f + RP} = \frac{1 - TR^{Sd-} \lambda_{t+1}^g h^m}{1 + r^f + RP}, \tag{C.18}$$

where λ^C is the overall probability (both ability and later willingness to pay) default, r^f is the risk-free rate and RP is an additive risk premium term that adjusts the alternative cost of investors to their own funding cost (assumed above the risk free rate). RP could be thought of as liquidity premia or any other factors (structural demand, risk aversion) that changes the alternative expected returns for investors discounted of government credit risk.

C.2.5 Model solution

The model is solved for recursive equilibria numerically by value function iteration. Recursive equilibria simultaneously satisfy government and investor optimization criteria for all states, thus it provides the vector of government policies for each state, where value functions are maximized given bond prices q and bond prices q which are also consistent with the government policies.

The procedure for the solution is:

- First, government value functions, V^{Sd} , of each state and debt and bond prices are initialized at ad hoc values.
- Then, in each iteration step: (a) bond prices are updated given the default policy and expectations of state transition in t^- according to equation C.18; (b) V is solved for optimal policy parameters given bond prices; (c) the transition matrices are updated; (d) calculate the difference of value functions and bond prices compared to the previous iteration.
- Iterations are ended, when the changes are less than a pre-specified convergence criterion.

There is a step I implement that significantly improves efficiency compared to the standard value function iteration procedure.

Proposition C.2. (*Value iteration shortcut*)

Consider the utility function $U_t = \sum_{h=0}^{\infty} \beta^h TR^h u_t$ with each period utility a function of state $s \in S$ that determines its dynamics $u(s')_{t+1} = p(s, s')u(s)_t$. Let the transition matrix $TR_{(S \times S)}$ be time-homogenous with elements in row i , column j of $TR_{S \times S}(i, j) = p(s, s')$.

Then:

- (i) the utility vector $u(S)$ that enumerates utilities for all states, can be written as $U(S)_t = u(S)_t + \sum_{h=1}^{\infty} \beta^h TR^h u(S)_t$.
- (ii) the stationary value function is given by $V(S)_t = \Phi^{-1}u(S)_t$ with $\Phi = I - \beta TR$ if Φ is invertible.

Proof. Appendix B.1. For (i) just iterate through and show that the limit exists and is of the given format. For (ii) introduce an operator similar to AR lag operator, and use the Leontieff inverse. The operator is also a change of measure. $\square$

Incorporating more stochastic elements

There are significantly more variables in this model than in other models of the extant literature and this requires a different solution approach. The standard quantitative models incorporate as state variables the output (deviation from trend), trend growth and the two policy variables of the debt ratio and repayment/default decision. The solution of the model uses the state-space

grid of these four variables and this is possible as the transition matrix of between states is still a manageable size.

The purposes of the thesis necessitate more variables to be included in the analysis. Fixing these at baseline values allows the standard solution technique outlined above. However, fixing and determining parameters a priori is unrealistic for two reasons. First, several parameters are not observable precisely (e.g α_2 , trend growth $\bar{g}$, h^g and many of the highly relevant parameters). Even if there are likely areas where such parameters are expected, there is still a large uncertainty surrounding these. Second, some parameters vary through time stochastically. These uncertainties are likely to play a role in both government and investor decisionmaking.

However, incorporating all variables with fully-fledged stochastics and dynamics would render this solution method unfeasible. Therefore I propose a different method.

I solve the model as discussed above with the stochastic dynamics due to $S - d$ (the seven states and debt ratio) individually for a large set of grid points on the space of other parameters. The grid points vary within the parameter allowed ranges discussed in the last chapter, and in most case only the minimum, baseline and maximum points are considered. I also set the standard deviation of SDV and CRV to 0.02 for these solutions.²¹

C.2.6 Fundamental effects on SDV and spreads

Table C.2 reports effects of fundamental parameters on SDV as well as interaction effects in a format similar to Tables 5.4 and Tables 6.1 in the case of Models I and II.

The baseline effects of most fundamental parameters are very similar to what is seen in previous models. Namely, all effect signs are the same as before. The magnitude of effects are roughly unchanged compared to Model II (see Tables 6.1) in the case of r^f (large positive effect of around 0.3-0.4), d , ψ , h^g (small negative effect of roughly -0.05), res (practically no effect), α_2 (large positive effect of 0.3-0.4) and ν_2 , ν_3 (small negative effects around -0.05). Similar to before, the effects of parameters on SDV appear smaller in absolute value in crisis regimes (FR and especially CR) compared to normal times.

The effects of $\bar{g}$, α_1 and ν_1 are substantially (around three times) larger than values in Model II. The large (even larger than Model II) negative effects of $\bar{g}$ and α_1 carry over the result of previous models that the government is reluctant to default in cases of high growth and preferences tilted toward deficit bias (high α_1). This is because high debt levels and high growth together allow large net bond issuances without increasing the debt ratio much, which is valuable when $\alpha_1 + \psi$ is positive. The utility resulting from net capital inflow and net issuances would be lost were the government to default, because this would exclude the government from the market reducing net issuance to zero. The government is still restricted to have primary balances within empirically observed ranges (-0.1, 0.05), which only permits a gradual running up of debt. The time that

²¹Solving first with sSDV and sCRV set to null for several parameter values identifies a range of SDV and CRV values based on which setting 0.02 appears to be a plausible initial guess.

the sovereign spends excluded from the market and the gradual nature of possible debt growth heavily discounts the utility that can be gained by defaulting with a large haircut and later running up debt again. This opportunism is the main motivation for sovereign defaults in the extant literature, but this incentive is significantly reduced in the current model, which restricts primary balances.

Table C.2: Fundamental baseline and interaction effects on SDV (Model III)

		Z_1 effect at baseline													
		$\bar{g}$	r^f	d	ψ	res	h^g	α_1	α_2	ν_1	ν_2	ν_3	d^{imf}	$sSDV$	c_1
$\partial SDVN$		-0.31	0.44	-0.08	-0.08	-0.01	-0.02	-0.54	0.45	-0.12	-0.07	-0.03	-0.00	0.31	0.33
$\partial SDVF$		-0.35	0.33	-0.09	0.11	-0.01	-0.02	-0.54	0.45	0.08	0.05	0.11	-0.00	0.19	0.21
$\partial SDVC$		-0.17	0.16	0.06	-0.10	-0.00	-0.03	-0.22	0.22	0.08	-0.08	-0.05	-0.15	0.07	0.07
		Z_1 effect at Z_2 minima and maxima													
Z_2		$\bar{g}$	r^f	d	ψ	res	h^g	α_1	α_2	ν_1	ν_2	ν_3	d^{imf}	$sSDV$	c_1
$\bar{g}$	min	-0.30	0.32	0.08	0.16	-0.07	0.23	-0.28	0.46	-0.07	-0.18	0.03	-0.01	0.20	0.22
	max	-0.30	0.22	-0.19	-0.31	-0.01	-0.10	-0.78	0.36	-0.12	-0.06	-0.03	-0.01	0.02	0.26
r^f	min	-0.23	0.42	-0.15	-0.28	-0.01	-0.08	-0.72	0.37	-0.12	-0.06	-0.02	-0.01	0.02	0.26
	max	-0.33	0.42	0.07	0.15	-0.12	0.17	-0.24	0.44	-0.22	-0.12	0.03	0.11	0.19	0.15
d	min	-0.20	0.29	-0.07	-0.17	-0.01	-0.00	-0.50	0.42	-0.11	-0.03	-0.02	-0.01	0.24	0.24
	max	-0.47	0.52	-0.07	0.15	-0.01	-0.05	-0.54	0.48	-0.10	-0.14	-0.03	-0.01	0.39	0.40
ψ	min	-0.15	0.15	-0.10	-0.08	-0.00	-0.02	-0.42	0.38	-0.11	-0.06	0.00	-0.01	0.20	0.21
	max	-0.62	0.58	0.22	-0.08	-0.14	0.41	-0.51	0.63	0.00	-0.06	-0.05	-0.06	0.38	0.47
res	min	-0.30	0.41	-0.07	-0.04	-0.01	-0.02	-0.52	0.47	-0.10	-0.07	-0.03	-0.01	0.29	0.31
	max	-0.24	0.29	-0.08	-0.18	-0.01	-0.02	-0.53	0.39	-0.11	-0.06	-0.03	-0.01	0.30	0.31
h^g	min	-0.22	0.25	-0.07	-0.17	-0.01	-0.02	-0.52	0.38	-0.11	-0.06	-0.02	-0.01	0.28	0.26
	max	-0.55	0.50	-0.11	0.26	-0.01	-0.02	-0.56	0.58	0.38	-0.10	-0.02	-0.01	0.32	0.35
α_1	min	0.01	-0.01	-0.05	0.05	-0.00	-0.01	-0.52	0.28	-0.14	-0.08	-0.05	-0.00	0.02	0.07
	max	-0.49	0.47	-0.09	-0.04	-0.01	-0.05	-0.52	0.39	-0.11	-0.08	-0.03	-0.03	0.02	0.49
α_2	min	-0.23	0.22	-0.08	-0.18	-0.01	-0.02	-0.52	0.44	-0.12	-0.05	-0.02	-0.00	0.01	0.28
	max	-0.32	0.29	-0.02	0.07	-0.09	0.18	-0.41	0.44	-0.09	-0.14	0.03	-0.00	0.20	0.19
ν_1	min	-0.24	0.38	-0.08	-0.16	-0.01	-0.02	-0.54	0.39	-0.10	-0.06	-0.02	-0.01	0.26	0.26
	max	-0.29	0.28	-0.06	-0.05	-0.02	0.47	-0.50	0.42	-0.10	-0.08	-0.04	-0.01	0.10	0.43
ν_2	min	-0.38	0.35	-0.01	-0.13	-0.01	0.01	-0.52	0.48	-0.10	-0.07	0.00	-0.01	0.23	0.25
	max	-0.27	0.29	-0.12	-0.13	-0.01	-0.02	-0.52	0.39	-0.12	-0.07	-0.04	-0.01	0.14	0.33
ν_3	min	-0.24	0.23	-0.07	-0.10	-0.01	-0.02	-0.53	0.37	-0.10	-0.05	-0.03	-0.01	0.26	0.26
	max	-0.29	0.28	-0.08	-0.15	-0.01	-0.02	-0.51	0.42	-0.11	-0.09	-0.03	-0.01	0.33	0.34
d^{imf}	min	-0.30	0.27	-0.08	-0.06	-0.01	-0.02	-0.51	0.44	-0.10	-0.07	-0.03	-0.01	0.32	0.35
	max	-0.30	0.39	-0.08	-0.12	-0.01	-0.02	-0.53	0.44	-0.11	-0.06	-0.02	-0.01	0.29	0.26
π_c	min	-0.40	0.37	-0.04	0.20	-0.01	0.27	-0.49	0.51	0.12	0.00	0.10	-0.01	0.25	0.27
	max	-0.23	0.22	-0.12	-0.38	-0.01	-0.02	-0.52	0.36	-0.56	-0.20	-0.17	-0.01	0.02	0.23
π_F	min	-0.25	0.24	-0.07	-0.15	-0.01	-0.02	-0.52	0.39	-0.14	-0.08	-0.05	-0.01	0.11	0.33
	max	-0.33	0.31	-0.08	0.13	-0.01	-0.03	-0.50	0.43	0.10	0.06	0.12	-0.01	0.18	0.19
$sSDV$	min	-0.24	0.23	-0.08	-0.17	-0.01	-0.02	-0.52	0.36	-0.10	-0.07	-0.02	-0.01	0.30	0.23
	max	-0.43	0.40	0.07	0.01	-0.00	0.03	-0.52	0.55	-0.26	-0.16	0.05	-0.04	0.30	0.00
c_0	min	-0.23	0.28	-0.09	-0.26	-0.00	-0.03	-0.54	0.37	-0.12	-0.06	-0.03	-0.01	0.31	0.31
	max	-0.19	0.17	0.08	0.01	0.00	0.06	-0.13	0.29	0.05	0.02	0.05	-0.09	0.08	0.31
c_1	min	-0.24	0.29	-0.09	-0.27	0.00	-0.03	-0.54	0.38	-0.11	-0.06	-0.03	-0.01	0.30	0.31
	max	-0.34	0.32	0.07	0.12	-0.25	0.23	-0.13	0.45	-0.15	-0.18	-0.03	-0.08	0.21	0.26
λ^z	min	-0.30	0.41	-0.07	0.19	-0.01	-0.02	-0.52	0.44	-0.10	-0.06	-0.03	-0.01	0.30	0.32
	max	-0.30	0.35	-0.07	-0.15	-0.01	-0.02	-0.52	0.45	-0.10	-0.07	-0.03	-0.01	0.30	0.27
β	min	-0.15	0.15	-0.03	-0.14	-0.00	-0.00	-0.26	0.27	-0.04	-0.02	-0.01	-0.00	0.10	0.11
	max	-0.48	0.61	-0.09	0.33	-0.02	-0.05	-0.68	0.49	-0.11	-0.09	-0.03	-0.01	0.42	0.44
T	min	-0.11	0.10	0.04	-0.03	0.00	-0.04	-0.17	0.15	-0.00	-0.00	-0.00	-0.06	0.05	0.05
	max	-0.46	0.50	-0.17	-0.29	-0.02	-0.01	-1.00	0.77	-0.22	-0.13	-0.02	-0.02	0.04	0.51

Sources: author's compilation.

Notes: The top panel reports table shows effects of fundamentals (Z_1) on overall SDV in the NR, FR and CR states. Effects larger than 0.05 in absolute value are highlighted. The rest of the table shows effects of Z_1 fundamentals on SDV (Z_1 , columns) at minimum and maximum values of other fundamentals (Z_2 , rows). Effects that are different from the baseline effect by at least 0.05 are highlighted.

Fundamental interactions remain important in Model III, moreover most of the interactions that

were important in Models I and II carry over. Due to the above explanation, trend growth and real interest rate effects are larger, when the debt ratio, the external share of debt, the haircut and deficit preference α_1 are larger. Just like before, when $\bar{g}$ or r^f move from the bottom to the top of their range, this causes the SDV effect to switch sign for d , ψ and h^g . For instance, the effect of d is significantly negative when trend growth is high and significantly positive, when trend growth is low.

As before, the effects of ν_2 , h^g and d increase together as either of these parameters are increased. This is the consequence of default-triggered output losses. Similarly to models in the previous chapter, the increase of π_c results in the effect of d and ψ decreasing. Also, β and T behave similarly. More patient households and longer crisis duration increase other parameter effects in absolute value.

In this model d_{imf} captures conditionality (instead of ν_4). Again, more strict conditionality (d_{imf} lower) results in higher SDV, because the government is not allowed to maintain high debt issuances, which reduces the benefit of remaining in the contract.

A key novelty in Model III is the introduction of sSDV, which allows studying the effects of (default) policy uncertainty. SDV increases in this parameter. The effect is larger, when trend growth minus interest rates are low (there are negative net issuances), when d and ψ are high. The effect of uncertainty is also larger when α_2 (social preference to default) is higher. These are cases, when SDV is already closer to the tipping point, in which case an increase in SDV volatility has a larger marginal impact.

Scenarios

Figure C.12 assesses how value functions at various states change by varying the debt ratio d , the external share of debt ψ and the funding liquidity crisis probability through c_1 .

With practically no funding liquidity probability ($c_1 = 0$, upper panel) the value of repayment states (V in NR, FR, CR) significantly exceed the value of default states²² (i.e SDV is negative), so the government chooses to repay. The value functions are increasing in d , so that the government is best off running up debt. The value functions are also higher in the external debt (upper right plot) than the domestic debt case (upper left plot), so that in this scenario the government would choose the debt to be externally issued. This is essentially the same prediction as in Model II.

Note also that default values are decreasing in debt in the domestic issuance case, which is the consequence of default-triggered output losses. The increase in value functions with respect to d in the external issuance case is inherited from the rise in the NR value function, because default ultimately – 2.5 years in expectation – results in switching to the NR regime.

The bottom panel of Figure C.12 turns to the funding liquidity crisis. Here, c_1 is assumed to take the maximum value of 10, which significantly increases the chance of a jump from NR or FR to

²² $V_{ND} = (1 - \pi_c)V_{NDn} + \pi_c V_{NDc}$ and $V_{CD} = (1 - \pi_c)V_{CDn} + \pi_c V_{CDc}$

Figure C.12: Value function levels by d , c_1 , ψ

Sources: author's compilation.

Notes: Value function levels of states (NR,FR,CR,ND,CD) (y-axis) are shown with respect to d (x-axis, percent) and low vs high values of ψ (0, 0.9) and c_1 (0, 10).

CR, moreover it also increases the probability of an unwanted default within the funding crisis state. As in Model II, this reverses government decisions on optimal debt issuance making low debt levels (values decrease in d) and domestic issuances (values are smaller in the high ψ case: right-hand plot) preferable.

Default is still not chosen by governments with domestic debt issuances (lower left-hand plot), nor would going to the IMF be strategically chosen, because the CR state has lower value than the FR state. However, defaults could happen accidentally, because the high c_1 increases the probability of a jump into the CR state and then into the CD state. This risk is highest for countries with low reserves and high debt according to the model.

Eurozone periphery countries in the sovereign crisis may fit this description. Although they had large domestically issued government debt (and so feared what a default may do to the banking sector), there was a risk of an evaporation of credit that effectively excluded these countries from the market and had them resort to international funding (entering the CR state even though this was unwanted). As [De Grauwe and Ji \(2013\)](#) argues, the reason for the distrust of investors was partly rooted in the perception that the ECB (and other EU institutions) failed to act as lenders of last resort. In the model, this is translated as a low res (available central bank reserves, i.e. help in funding), which in a time of high c_1 greatly increases λ^l , the parameter that controls the chance of a funding crisis and a non-strategic default, especially for highly indebted countries. Supporting these claims, when Mario Draghi asserted that the ECB will provide last resort funding to these countries (effectively increasing res), the perceived probability of default declined, bond prices

recovered and market trust returned.

A funding liquidity stress has different implications for externally indebted countries (lower right plot). In these cases the value of FR already sinks below CR for lower debt levels, because a currency crisis takes its toll on foreign currency liabilities and IMF help in stemming the currency rise becomes a favored option even with its implied austerity. If the country turns to the IMF, strategic default is again off the cards (the value of CD is much lower), but accidental defaults may still occur. Above a certain debt level (around 60 percent of output in these settings) IMF help becomes unwanted and the government instead chooses to default.

C.2.7 Model implications

In sum, Model III confirms most results of Chapters 5 and 6. This is important, because interest rate endogeneity, debt ratio endogeneity and infinite horizon with annual dynamics (rather than the short-long term structure before) could have hampered some of the previously recovered results.

Model III also provides a better framework to study aspects of policy uncertainty, the political economy nexus and the role of conditionality in international assistance on both the borrowing and default decisions. However, this analysis is yet incomplete and is left for future work.

C.3 Monte Carlo exercise: further tables

This section presents further tables and results of the Monte Carlo exercise that is used to choose between estimation techniques and tests of time-variation.

Table C.3 reports rejection rates based on various tests, when the true effect is time-invariant. In these cases close to zero rejection rates are preferred, because rejection constitutes false negatives (Type I error), i.e. the erroneous conclusion from tests that the effect is time-variant. As seen from the table, F-tests and Likelihood Ratio-tests²³ tend to have lower rejection rates than Wald-tests or model selection based on information criteria, especially the Akaike Information Criteria.

Table C.4-C.6 report rejection rates based on F-tests for various model and parameter settings. The columns β_0 can be regarded the size of tests, while other columns inform about the power of tests against the alternatives.

Tables C.7-C.9 report root mean squared errors of the estimated effects as measures of model fit. Table C.10 reports root mean squared errors of the cross-sectional variance share estimates of the X1 fundamental.

Table C.3: Size of various tests regarding the null of time-invariant effects

	Test statistic used:	F 5%	LR 5%	W 5%	AIC	BIC
Modelled $\hat{\beta}$	Model spec.					
PANEL A: Observed fundamentals, Z_2 included						
period	Levels 2	0.000	0.000	1.000	0.882	0.120
period	Levels 3	0.000	0.000	1.000	0.900	0.110
period	Levels 4	0.000	0.280	0.260	0.402	0.277
period	Levels 5	0.000	0.360	0.340	0.415	0.302
crisis	Diffs 7	0.070	0.080	0.960	0.805	0.007
RP	Diffs 7	0.210	0.200	0.960	0.805	0.007
PANEL B: Observed fundamentals, Z_2 omitted						
period	Levels 2	0.450	0.500	1.000	0.882	0.120
period	Levels 3	0.520	0.470	1.000	0.900	0.110
period	Levels 4	0.000	0.370	0.360	0.402	0.277
period	Levels 5	0.000	0.410	0.260	0.415	0.302
crisis	Diffs 7	0.080	0.100	0.960	0.805	0.007
RP	Diffs 7	0.030	0.040	0.970	0.805	0.007
PANEL C: Noisy fundamental proxies, Z_2 included						
period	Levels 2	0.980	0.980	1.000	0.917	0.292
period	Levels 3	0.620	0.540	1.000	0.867	0.278
period	Levels 4	0.130	0.330	0.310	0.485	0.250
period	Levels 5	0.000	0.400	0.240	0.510	0.215
crisis	Diffs 7	0.100	0.100	0.960	0.827	0.007
RP	Diffs 7	0.120	0.100	0.970	0.827	0.007
PANEL D: Noisy fundamental proxies, Z_2 omitted						
period	Levels 2	0.450	0.550	1.000	0.917	0.292

²³The Likelihood Ratio-tests are calculated differently from the way included in most softwares, because I also allow for cross-section heterogeneity of variances. Without allowing heteroscedasticity, LR-test results would be nearly identical to the F-test results published, because the number of observations are large. Therefore the better attributes of the F-test follow from the more parsimonious restrictive specification and not the difference between the testing method.

	Test statistic used:	F 5%	LR 5%	W 5%	AIC	BIC
Modelled $\hat{\beta}$	Model spec.					
period	Levels 3	0.450	0.400	1.000	0.867	0.278
period	Levels 4	0.030	0.390	0.330	0.485	0.250
period	Levels 5	0.000	0.410	0.240	0.510	0.215
crisis	Diffs 7	0.110	0.120	1.000	0.827	0.007
RP	Diffs 7	0.070	0.080	1.000	0.827	0.007

Sources: author's compilation.

Notes: The table reports rejection rates of the null hypothesis of time-invariance various tests (F: F-test, LR: Likelihood ratio with heteroskedastic errors, W: Wald-test, AIC/BIC: model selection based on information criteria: i.e would return time-invariance if information criteria for the time-invariant model was lower than the time-variant model) in Monte Carlo simulations (100 simulations), when the true data generating process has time-invariant β . Therefore the table assesses the size of tests (Type I error rates). Close to zero rejection rates are preferred in these cases. See Table 9.2 notes for row and panel definitions.

Table C.4: F-test rejection rates (Observed fundamentals)

Z_2 in model:	Z_2 included				Z_2 omitted			
TRUE β :	β_0	β_C	βRP_t	β_t	β_0	β_C	βRP_t	β_t
Model spec.								
PANEL A: $\hat{\beta}$ crisis-dependent								
Levels 1	0.540	1.000	0.950	1.000	0.180	1.000	0.720	1.000
Levels 2	0.000	1.000	0.980	1.000	0.610	1.000	0.820	1.000
Levels 3	0.000	1.000	0.990	1.000	0.510	1.000	0.900	1.000
Levels 4	0.280	1.000	0.990	1.000	0.150	1.000	0.790	1.000
Levels 5	0.310	1.000	0.990	1.000	0.070	1.000	0.840	1.000
Diffs 6	0.120	1.000	0.340	1.000	0.150	1.000	0.350	1.000
Diffs 7	0.070	1.000	0.250	0.990	0.080	1.000	0.360	0.750
Diffs 8	0.120	1.000	0.440	1.000	0.060	1.000	0.050	1.000
Diffs 9	0.250	1.000	0.260	1.000	0.050	1.000	0.000	0.910
Diffs 10	0.000	1.000	0.710	1.000	0.470	1.000	0.370	1.000
PANEL B: $\hat{\beta}$ RP-dependent								
Levels 1	0.990	1.000	1.000	0.990	0.680	0.740	0.990	0.900
Levels 2	0.010	0.930	1.000	0.990	0.520	0.910	1.000	0.960
Levels 3	0.010	0.940	1.000	0.990	0.590	0.910	1.000	0.960
Levels 4	0.350	0.860	1.000	0.960	0.210	0.810	1.000	0.930
Levels 5	0.340	0.860	0.990	0.970	0.210	0.830	1.000	0.920
Diffs 6	0.220	0.810	0.980	0.910	0.100	0.700	0.920	0.910
Diffs 7	0.210	0.740	0.970	0.920	0.030	0.550	0.360	0.930
Diffs 8	0.370	0.900	1.000	0.930	0.010	0.550	1.000	0.850
Diffs 9	1.000	1.000	1.000	1.000	0.280	0.510	0.970	0.860
Diffs 10	0.010	0.920	1.000	0.930	0.280	0.780	1.000	0.910
PANEL C: $\hat{\beta}$ period-dependent								
Levels 1	0.680	1.000	1.000	1.000	0.130	1.000	1.000	1.000
Levels 2	0.000	1.000	1.000	1.000	0.450	1.000	1.000	1.000
Levels 3	0.000	1.000	1.000	1.000	0.520	1.000	1.000	1.000
Levels 4	0.000	1.000	1.000	1.000	0.000	1.000	1.000	1.000
Levels 5	0.000	1.000	1.000	1.000	0.000	1.000	1.000	1.000
Diffs 6	1.000	1.000	1.000	1.000	0.240	1.000	1.000	1.000
Diffs 7	0.240	1.000	1.000	1.000	0.250	1.000	1.000	1.000
Diffs 8	1.000	1.000	1.000	1.000	0.320	1.000	1.000	1.000
Diffs 9	1.000	1.000	1.000	1.000	0.330	1.000	0.990	1.000
Diffs 10	0.000	1.000	1.000	1.000	0.370	1.000	1.000	1.000

Sources: author's compilation.

Notes: The table reports rejection rates of the null hypothesis of time-invariance based on the Likelihood ratio-test at 5 percent significance level in Monte Carlo simulations (100 simulations) when fundamentals are perfectly observed via proxies. The column heads refer to the true data generating process regarding the true effect, β and left-right panels: whether the Z_2 proxy is included. Rows correspond to different model specifications and panels refer to the estimated effect specification, $\hat{\beta}$. Close to zero rejection rates are

Z_2 in model:	Z_2 included				Z_2 omitted			
TRUE β : Model spec.	β_0	β_C	$\beta R P_t$	β_t	β_0	β_C	$\beta R P_t$	β_t
Levels 2	0.860	1.000	1.000	1.000	0.660	1.000	1.000	1.000
Levels 3	0.850	1.000	1.000	1.000	0.710	1.000	1.000	1.000
Levels 4	0.790	1.000	1.000	1.000	0.160	1.000	1.000	1.000
Levels 5	0.800	1.000	1.000	1.000	0.140	1.000	1.000	1.000
PANEL C: Cholesky-regression								
Levels 2	0.840	1.000	1.000	1.000	0.660	1.000	1.000	1.000
Levels 3	0.870	1.000	1.000	1.000	0.720	1.000	1.000	1.000
Levels 4	0.800	1.000	1.000	1.000	0.190	1.000	1.000	1.000
Levels 5	0.790	1.000	1.000	1.000	0.170	1.000	1.000	1.000
PANEL D: PCA regression								
Levels 2	0.850	1.000	1.000	1.000	0.520	1.000	1.000	1.000
Levels 3	0.720	1.000	1.000	1.000	0.510	1.000	1.000	1.000
Levels 4	0.150	1.000	1.000	1.000	0.010	1.000	1.000	1.000
Levels 5	0.150	1.000	1.000	1.000	0.030	1.000	1.000	1.000
PANEL E: Procrustes regression								
Levels 2	0.820	1.000	1.000	1.000	0.480	1.000	1.000	1.000
Levels 3	0.710	1.000	1.000	1.000	0.500	1.000	1.000	1.000
Levels 4	0.090	1.000	1.000	1.000	0.010	0.990	0.990	0.990
Levels 5	0.090	1.000	1.000	1.000	0.000	0.980	1.000	0.970

Sources: author's compilation.

Notes: The table reports rejection rates of the null hypothesis of time-invariance based on the F-test at 5 percent significance level in Monte Carlo simulations (100 simulations), when fundamentals are observed via correlated noisy proxies. The left panel corresponds to the more inclusive specifications that include proxies for both X_1 and X_2 , the right panel only includes proxies for X_1 . Panel B has the specifications Z_1 - Z_6 (left), Z_1 , Z_3 (right); Panel C includes Cholesky decomposed variables of Z_1 - Z_6 in this order (left), Z_1 , Z_3 (right); Panel D includes the first PC of Z_2, Z_4 (left) and the first PC of Z_1, Z_3 (both left, right). Panel E uses Procrustes factors of Z_1 - Z_6 given by a rotation to a loading target matrix that has ones for the X_1 factor Z_1, Z_3 , and zeros for Z_2, Z_4 and the reverse loading targets for X_2 (see [Kocsis, 2014](#), for elaboration on the methodology).

Table C.7: RMSE of estimated effect (Observed fundamentals)

Z_2 in model:	Z_2 included				Z_2 omitted			
TRUE β : Model spec.	β_0	β_C	$\beta R P_t$	β_t	β_0	β_C	$\beta R P_t$	β_t
PANEL A: $\hat{\beta}$ crisis-dependent								
Levels 1	0.053	0.023	0.047	0.025	0.057	0.035	0.057	0.033
Levels 2	0.119	0.001	0.117	0.031	0.116	0.041	0.121	0.046
Levels 3	0.117	0.001	0.114	0.031	0.116	0.040	0.119	0.046
Levels 4	0.053	0.023	0.047	0.025	0.057	0.035	0.058	0.033
Levels 5	0.053	0.023	0.048	0.025	0.057	0.035	0.058	0.033
Diffs 6	0.136	0.046	0.453	0.155	0.186	0.136	0.859	0.255
Diffs 7	0.085	0.043	0.133	0.105	0.110	0.133	0.532	0.214
Diffs 8	0.060	0.024	0.061	0.042	0.068	0.049	0.097	0.075
Diffs 9	0.063	0.026	0.065	0.049	0.075	0.064	0.117	0.105
Diffs 10	0.097	0.001	0.137	0.051	0.094	0.057	0.185	0.094
PANEL B: $\hat{\beta}$ RP-dependent								
Levels 1	0.049	0.025	0.032	0.027	0.053	0.037	0.045	0.035
Levels 2	0.117	0.051	0.072	0.056	0.116	0.068	0.099	0.068
Levels 3	0.117	0.051	0.070	0.056	0.116	0.065	0.091	0.067
Levels 4	0.049	0.025	0.031	0.027	0.053	0.037	0.044	0.034

Z_2 in model:	Z_2 included				Z_2 omitted			
TRUE β : Model spec.	β_0	β_C	βRP_t	β_t	β_0	β_C	βRP_t	β_t
Levels 5	0.049	0.025	0.032	0.027	0.053	0.037	0.044	0.034
Diffs 6	0.126	0.178	0.286	0.216	0.174	0.342	0.680	0.326
Diffs 7	0.064	0.092	0.078	0.086	0.082	0.295	0.398	0.163
Diffs 8	0.048	0.037	0.036	0.042	0.054	0.080	0.062	0.067
Diffs 9	0.050	0.041	0.037	0.046	0.058	0.112	0.075	0.088
Diffs 10	0.095	0.068	0.081	0.088	0.093	0.122	0.145	0.137

PANEL C: $\hat{\beta}$ period-dependent								
Levels 1	0.048	0.024	0.024	0.024	0.053	0.037	0.040	0.034
Levels 2	0.118	0.001	0.001	0.001	0.117	0.042	0.071	0.038
Levels 3	0.117	0.001	0.001	0.001	0.116	0.041	0.064	0.037
Levels 4	0.048	0.024	0.024	0.024	0.053	0.037	0.039	0.034
Levels 5	0.049	0.024	0.024	0.024	0.053	0.037	0.039	0.034
Diffs 6	0.135	0.246	24.598	0.648	0.201	0.226	0.510	0.190
Diffs 7	0.212	0.369	0.402	0.312	0.173	0.255	0.393	0.177
Diffs 8	0.094	0.250	1.143	0.425	0.150	0.097	0.093	0.093
Diffs 9	0.274	0.329	0.401	0.318	0.170	0.118	0.138	0.097
Diffs 10	0.128	0.247	23.198	0.587	0.124	0.071	0.111	0.073
EM 11	0.096	0.029	0.081	0.031	0.117	0.060	0.092	0.050
EM 12	0.322	0.234	0.206	0.264	0.316	0.379	0.545	0.243
EM 13	0.073	0.043	0.211	0.047	0.075	0.168	0.166	0.093
EM 14	0.057	0.055	0.101	0.046	0.073	0.236	0.346	0.112
EM 15	0.075	0.044	0.213	0.048	0.072	0.166	0.163	0.092
EM 16	0.056	0.055	0.102	0.047	0.072	0.234	0.332	0.112
EM 17	0.066	0.024	0.032	0.025	0.059	0.038	0.064	0.037
EM 18	0.054	0.023	0.026	0.023	0.050	0.036	0.042	0.033
EM 19	0.046	0.024	0.026	0.023	0.047	0.037	0.050	0.033
EM 20	0.047	0.025	0.027	0.024	0.047	0.037	0.048	0.033
EM 21	0.046	0.025	0.027	0.024	0.048	0.037	0.050	0.033

Sources: author's compilation.

Notes: The table reports root mean squared errors of the β_1 effect in Monte Carlo simulations (100 simulations), when fundamentals are perfectly observed via proxies. See other notes in Table C.4.

Table C.8: RMSE of estimated effect (Noisy proxies of fundamentals)

Z_2 in model:	Z_2 included				Z_2 omitted			
TRUE β : Model spec.	β_0	β_C	βRP_t	β_t	β_0	β_C	βRP_t	β_t

PANEL A: $\hat{\beta}$ crisis-dependent								
Levels 1	0.024	0.033	0.031	0.031	0.031	0.042	0.042	0.039
Levels 2	0.140	0.127	0.222	0.147	0.139	0.128	0.223	0.147
Levels 3	0.140	0.127	0.216	0.148	0.140	0.128	0.219	0.149
Levels 4	0.024	0.033	0.031	0.031	0.030	0.042	0.042	0.038
Levels 5	0.024	0.033	0.030	0.031	0.031	0.042	0.042	0.039
Diffs 6	0.106	0.111	0.776	0.137	0.133	0.179	0.983	0.193
Diffs 7	0.035	0.106	0.685	0.172	0.053	0.274	12.070	0.261
Diffs 8	0.025	0.026	0.078	0.035	0.033	0.054	0.231	0.064
Diffs 9	0.026	0.030	0.123	0.050	0.035	0.079	0.418	0.097
Diffs 10	0.122	0.111	0.194	0.122	0.117	0.110	0.205	0.118

PANEL B: $\hat{\beta}$ RP-dependent								
Levels 1	0.024	0.031	0.042	0.028	0.031	0.041	0.050	0.036
Levels 2	0.138	0.125	0.207	0.147	0.138	0.128	0.215	0.147
Levels 3	0.139	0.124	0.203	0.147	0.139	0.126	0.211	0.148
Levels 4	0.024	0.031	0.042	0.028	0.031	0.041	0.050	0.036
Levels 5	0.024	0.031	0.042	0.028	0.031	0.041	0.050	0.036
Diffs 6	0.104	0.202	0.274	0.213	0.133	0.348	0.484	0.303

Z_2 in model:	Z_2 included				Z_2 omitted			
TRUE β : Model spec.	β_0	β_C	βRP_t	β_t	β_0	β_C	βRP_t	β_t
Diffs 7	0.034	0.200	0.242	0.181	0.050	0.514	109.359	0.265
Diffs 8	0.025	0.034	0.048	0.039	0.032	0.077	0.152	0.067
Diffs 9	0.027	0.045	0.058	0.054	0.038	0.123	0.253	0.098
Diffs 10	0.119	0.112	0.171	0.127	0.115	0.121	0.183	0.130
PANEL C: $\hat{\beta}$ period-dependent								
Levels 1	0.025	0.033	0.060	0.029	0.032	0.044	0.065	0.039
Levels 2	0.139	0.127	0.204	0.142	0.139	0.129	0.214	0.142
Levels 3	0.139	0.126	0.205	0.141	0.138	0.127	0.211	0.143
Levels 4	0.025	0.033	0.060	0.029	0.031	0.043	0.065	0.038
Levels 5	0.025	0.033	0.060	0.029	0.032	0.043	0.065	0.038
Diffs 6	0.148	0.151	0.166	0.275	0.161	0.235	0.451	0.211
Diffs 7	0.215	0.744	0.325	0.184	0.097	0.321	457.777	0.198
Diffs 8	0.324	0.102	0.095	0.162	0.088	0.111	0.157	0.211
Diffs 9	0.121	0.649	0.205	0.160	0.093	0.130	0.313	0.137
Diffs 10	0.153	0.149	0.191	0.315	0.137	0.157	0.216	0.172
EM 11	0.041	0.044	0.060	0.053	0.037	0.053	0.158	0.051
EM 12	0.144	0.210	0.302	0.188	0.147	0.321	12.065	0.205
EM 13	0.066	0.049	0.102	0.074	0.087	0.117	8.806	0.052
EM 14	0.070	0.070	0.235	0.054	0.073	0.238	115.427	0.083
EM 15	0.066	0.048	0.098	0.073	0.088	0.111	56.887	0.050
EM 16	0.070	0.066	0.228	0.051	0.073	0.229	14.245	0.082
EM 17	0.028	0.034	0.050	0.032	0.037	0.049	0.059	0.042
EM 18	0.024	0.031	0.059	0.028	0.031	0.041	0.068	0.037
EM 19	0.025	0.032	0.062	0.028	0.029	0.041	0.086	0.036
EM 20	0.025	0.032	0.060	0.028	0.029	0.041	0.084	0.036
EM 21	0.025	0.032	0.061	0.028	0.029	0.041	0.085	0.036

Sources: author's compilation.

Notes: The table reports root mean squared errors of the β_1 effect in Monte Carlo simulations (100 simulations), when fundamentals are observed via noisy proxies. See other notes in Table C.4.

Table C.9: RMSE of estimated effect (Correlated noisy proxies)

Z_2 in model:	Z_2 included				Z_2 omitted			
TRUE β : Model spec.	β_0	β_C	βRP_t	β_t	β_0	β_C	βRP_t	β_t
PANEL A: Z_1 only								
Levels 2	NaN	NaN	NaN	NaN	0.383	0.331	0.543	0.409
Levels 3	NaN	NaN	NaN	NaN	0.383	0.331	0.543	0.409
Levels 4	NaN	NaN	NaN	NaN	0.095	0.081	0.127	0.098
Levels 5	NaN	NaN	NaN	NaN	0.094	0.080	0.124	0.096
EM 13	NaN	NaN	NaN	NaN	0.193	0.855	3.194	11.259
EM 19	NaN	NaN	NaN	NaN	0.091	0.086	0.125	0.090
PANEL B: full specification								
Levels 2	0.384	0.332	0.542	0.410	0.384	0.327	0.532	0.403
Levels 3	0.384	0.331	0.542	0.410	0.384	0.327	0.533	0.403
Levels 4	0.219	0.192	0.308	0.232	0.205	0.172	0.275	0.210
Levels 5	0.218	0.190	0.307	0.231	0.204	0.171	0.273	0.209
EM 13	0.281	1.208	0.722	0.297	0.273	0.294	2.574	0.328
EM 19	0.211	0.184	0.289	0.220	0.200	0.174	0.272	0.206
PANEL C: Cholesky-regression								
Levels 2	0.374	0.321	0.527	0.398	0.375	0.322	0.528	0.399
Levels 3	0.374	0.321	0.528	0.398	0.375	0.322	0.529	0.399
Levels 4	0.096	0.082	0.128	0.099	0.095	0.081	0.126	0.097
Levels 5	0.095	0.081	0.127	0.098	0.094	0.080	0.125	0.096
EM 13	0.281	1.208	0.722	0.297	0.198	1.834	4.283	10.749

Z_2 in model:	Z_2 included				Z_2 omitted			
TRUE β : Model spec.	β_0	β_C	βRP_t	β_t	β_0	β_C	βRP_t	β_t
EM 19	0.211	0.184	0.289	0.220	0.098	0.094	0.136	0.102
PANEL D: PCA regression								
Levels 2	0.372	0.320	0.523	0.397	0.372	0.320	0.525	0.397
Levels 3	0.372	0.320	0.525	0.398	0.372	0.320	0.526	0.397
Levels 4	0.085	0.077	0.114	0.088	0.074	0.064	0.098	0.076
Levels 5	0.084	0.077	0.113	0.087	0.074	0.064	0.097	0.075
EM 13	0.171	0.615	0.914	2.378	0.203	10.094	5.101	1.916
EM 19	0.082	0.078	0.114	0.086	0.096	0.086	0.125	0.098
PANEL E: Procrustes regression								
Levels 2	0.371	0.318	0.522	0.395	0.374	0.321	0.526	0.398
Levels 3	0.372	0.318	0.523	0.395	0.374	0.321	0.527	0.398
Levels 4	0.094	0.077	0.123	0.095	0.093	0.076	0.121	0.094
Levels 5	0.093	0.076	0.122	0.094	0.092	0.075	0.120	0.093
EM 13	0.188	13.422	1.255	6.307	0.203	10.094	5.101	1.916
EM 19	0.092	0.081	0.126	0.094	0.096	0.086	0.125	0.098

Sources: author's compilation.

Notes: The table reports root mean squared errors of the β_1 effect in Monte Carlo simulations (100 simulations), when fundamentals are observed via correlated noisy proxies. See other notes in Table C.6.

Table C.10: RMSE of estimated X1 variance share (Correlated noisy proxies)

Z_2 in model:	Z_2 included				Z_2 omitted			
TRUE β : Model spec.	β_0	β_C	βRP_t	β_t	β_0	β_C	βRP_t	β_t
PANEL A: Z_1 only								
Levels 2	NaN	NaN	NaN	NaN	0.342	0.878	1.139	1.011
Levels 3	NaN	NaN	NaN	NaN	0.342	0.879	1.151	1.011
Levels 4	NaN	NaN	NaN	NaN	0.049	0.035	0.051	0.034
Levels 5	NaN	NaN	NaN	NaN	0.049	0.035	0.050	0.034
EM 13	NaN	NaN	NaN	NaN	0.194	0.227	0.669	0.480
EM 19	NaN	NaN	NaN	NaN	0.049	0.035	0.051	0.035
PANEL B: full specification								
Levels 2	0.229	0.689	0.858	0.770	0.108	0.636	0.887	0.709
Levels 3	0.222	0.654	0.868	0.751	0.117	0.609	0.913	0.702
Levels 4	0.030	0.023	0.032	0.020	0.028	0.022	0.029	0.018
Levels 5	0.030	0.023	0.032	0.020	0.028	0.022	0.029	0.018
EM 13	0.193	0.047	0.360	0.078	0.169	0.043	0.496	0.074
EM 19	0.029	0.022	0.030	0.018	0.028	0.022	0.030	0.018
PANEL C: Cholesky-regression								
Levels 2	0.210	0.671	0.845	0.746	0.136	0.651	0.901	0.726
Levels 3	0.233	0.639	0.855	0.722	0.126	0.623	0.926	0.718
Levels 4	0.032	0.024	0.035	0.021	0.030	0.023	0.031	0.019
Levels 5	0.032	0.024	0.035	0.021	0.030	0.023	0.031	0.019
EM 13	0.389	0.149	0.393	0.248	0.247	0.302	0.526	0.549
EM 19	0.047	0.034	0.049	0.034	0.029	0.048	0.023	0.023
PANEL D: PCA regression								
Levels 2	0.081	0.632	0.855	0.714	0.083	0.614	0.870	0.694
Levels 3	0.091	0.594	0.862	0.707	0.103	0.589	0.891	0.691
Levels 4	0.032	0.023	0.033	0.019	0.032	0.023	0.033	0.020
Levels 5	0.032	0.022	0.033	0.019	0.032	0.023	0.033	0.019
EM 13	0.185	0.043	0.385	0.179	0.280	0.319	0.637	0.380
EM 19	0.032	0.022	0.033	0.019	0.090	0.065	0.088	0.074

Z_2 in model: TRUE β : Model spec.	Z_2 included				Z_2 omitted			
	β_0	β_C	βRP_t	β_t	β_0	β_C	βRP_t	β_t
PANEL E: Procrustes regression								
Levels 2	0.131	0.645	0.856	0.728	0.201	0.710	0.922	0.804
Levels 3	0.196	0.625	0.873	0.719	0.212	0.700	0.942	0.809
Levels 4	0.090	0.066	0.089	0.075	0.090	0.066	0.088	0.074
Levels 5	0.090	0.066	0.089	0.075	0.090	0.066	0.088	0.074
EM 13	0.092	0.234	0.380	0.386	0.280	0.319	0.637	0.380
EM 19	0.090	0.066	0.089	0.075	0.090	0.065	0.088	0.074

Sources: author's compilation.

Notes: The table reports root mean squared errors of the variance share estimates of the X_1 fundamental in the cross-sectional variance of the dependent in Monte Carlo simulations (100 simulations), when fundamentals are observed via correlated noisy proxies. See other notes in Table C.6.