Sovereign borrowing and sovereign default

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Introduction

In the course of the global financial crisis, countries that did not experience a sovereign debt crisis for several decades suddenly faced increasing sovereign default risk spreads as investors started to doubt the sustainability of fiscal positions. Several European countries struggled to avoid a government default and Greece defaulted in 2012. The three chapters of this thesis analyze several important questions related to sovereign borrowing and sovereign default risk that have received much attention in the wake of the European sovereign debt crisis. Chapter 1 builds on the observation that twin deficits, that is the simultaneous deficit of the fiscal balance and the current account, occurred in several European countries in the years before and during the global financial crisis. These observations revived the debate about whether increasing fiscal deficits cause larger current account imbalances. The first chapter analyzes, both empirically and theoretically, how the occurrence of twin deficits depends on the indebtedness of the government. Chapter 2 relates to the European sovereign debt crisis during which the International Monetary Fund (IMF) together with the European Stability Mechanism (ESM) and its predecessors provided financial assistance to countries facing financial distress. The second chapter investigates within a quantitative model of sovereign default how the provision of financial assistance by a supranational agency affects the probability of a government default. Chapter 3 analyzes the impact of pegging a country's currency on sovereign default incentives. Following the announcement of the introduction of the Euro sovereign risk spreads decreased in several European countries. Lower spreads might have favored sovereign debt accumulation in the following years. The third chapter employs a quantitative model of sovereign default to study how pegging the currency, and thereby reducing the flexibility when faced with sovereign debt crises, affects sovereign debt levels and the default probability of the government. The remainder of this introduction provides more details about the three chapters of this dissertation.

CHAPTER 1. The first chapter is based on joint work with Patrick Hürtgen. The chapter examines whether the co-movement of the fiscal balance and the current account depends on the government debt-to-GDP ratio. The possible consequences of rising public debt stocks in many European countries have received much attention in the recent policy debate. In the euro zone the average government debt-to-GDP ratio increased from 70 percent in 2008 to 90 percent in 2012. Before and at the beginning of the global financial crisis of 2007-09 several southern European countries experienced increasing fiscal deficits and widening current account imbalances. These observations have rekindled the issue of possible causal linkages between the fiscal balance and the current account — a debate that has received much attention since the observation of twin deficits in the U.S. economy in the 1980s. Since 2008-09, despite protracted fiscal deficits, the current accounts of southern European countries have been rebalancing sharply, suggesting that the link between the twin deficits has diminished.

In the first part of the analysis in Chapter 1 a dynamic panel threshold model for 15 European countries is estimated to quantify the influence of sovereign indebtedness on the relationship between the fiscal balance and the current account. The employed method allows for the estimation of a threshold value of sovereign debt at which the co-movement of the two balances changes. Below the estimated threshold of 72 percent government debt-to-GDP a significant, positive relationship between the fiscal balance and the current account is found, whereas above the threshold the partial correlation is insignificant with a point estimate around zero. Splitting the sample into observations below and above the estimated threshold shows that the correlation of the two balances falls by 0.19 when moving from the low government debt regime to the high government debt regime. The second part of the analysis provides a structural explanation for the empirical evidence based on a small open economy model allowing for the possibility of sovereign default. High government debt-to-GDP ratios raise non-linear sovereign default risk premia due to the increasing probability of government default and lead to higher expected labor tax rates. In the case of a sovereign default, however, a haircut lowers the government debt-to-GDP ratio and expected labor tax rates fall. Households are therefore faced with a higher uncertainty about future taxes at high government debt-to-GDP ratios. Optimizing households increase their saving while fiscal deficits are expanding, leading to less pronounced current account deficits. The model-based correlation of the fiscal balance and the current account declines by 0.15 when moving from a low government debt regime to a high government debt regime, in line with the empirical evidence.

Chapter 2. The second chapter builds on joint work with Florian Kirsch (Kirsch and Rühmkorf, 2013). While there is a long history of sovereign debt crises and financial assistance in emerging economies, the policy debate about the impact of financial assistance has attracted increasing attention in the course of the European sovereign debt crisis. This chapter analyzes the impact of the provision of financial assistance by official lenders like the IMF on the debt level and the default probability of borrowing governments.

The provision of financial assistance might help to avoid a default by the government in two different ways. First, a default of the government can be triggered by a run by investors on the market for government debt. Runs on sovereign debt markets constitute a major threat for indebted governments as they can push countries into default that have in principle sound fundamentals and would not default otherwise. An official lending facility can help to prevent the possible coordination failure as financial assistance supplies the government with funds even in the case of a run by private investors. Second, a government might default because of bad fundamentals like low output and high debt levels. Sovereign spreads rise as investors demand a compensation for the default risk which increases refinancing costs of the government. In this case the provision of financial assistance can help to bridge crisis periods by lowering refinancing costs of the government and avoid a default in this way. In both cases, the provision of financial assistance lowers the default probability for a given level of government debt. In equilibrium, the smaller default probability translates into lower sovereign risk spreads for given levels of government debt. The lower borrowing costs might, however, induce the government to accumulate higher debt levels and thus increase default incentives.

To assess the overall effect of the availability of financial assistance on the probability of default the second chapter considers a quantitative model of endogenous credit structure and sovereign default that allows for both defaults due to self-fulfilling expectations and defaults due to bad fundamentals. The model features an official lending facility that captures the main characteristics of actual international financial institutions. For the quantitative analysis the model is calibrated to Argentinean data. Comparing the benchmark model to a version of the model in which the government does not have access to financial assistance reveals that the availability of financial assistance reduces the number of defaults that occur due to self-fulfilling runs by private investors. However, at the same time it raises average debt levels and causes an overall increase of the probability of default.

CHAPTER 3. The third chapter studies how the option to devalue the currency to reduce the debt burden affects the average debt level and the default incentives of the government. While some governments borrow from foreign investors in foreign currency, many governments borrow from foreign investors primarily in domestic currency. Borrowing in domestic currency provides the government with the option to partially default on its debt by devaluing its currency. However, a devaluation is costly as it typically triggers a temporary deterioration of the terms of trade. The option to devalue gives the government a higher degree of flexibility and might reduce the frequency of outright defaults. In contrast, pegging the exchange rate to a foreign currency (for example by establishing a currency board), dollarizing the economy or borrowing in foreign currency deprives the government of the option to devalue its currency to reduce the real debt burden and might therefore increase the default probability.

To analyze the impact of the option to devalue on average debt levels and the default probability a quantitative model of sovereign default and devaluation is considered. The model is calibrated to Argentinean data from the time before the establishment of the currency board in 1991. The benchmark model is compared with a model version in which the option to devalue is eliminated. Simulations of the two models show that average debt is higher when the government cannot devalue. The elimination of devaluation risk leads to lower sovereign spreads at low government debt levels. Lower sovereign spreads induce the government to accumulate larger amounts of debt. The probability of a sovereign default and the average spread increase. This is due to both higher average debt levels and a lower flexibility when facing sovereign debt crisis as the option to devalue to lower the value of the debt burden is not existent anymore.

The findings of the third chapter are in line with the experience of several southern European countries that adopted the Euro: Around the time that the introduction of the Euro was accounced spreads started to fall, while sovereign spreads increased again during the financial crisis, presumably due to higher default risk. The results of this chapter also shed light on the debate about the 'original sin'. When the government has the option to devalue its debt, sovereign spreads for given debt levels are higher due to the devaluation risk. The higher borrowing costs endogenously reduce government debt levels. The government therefore borrows on average less from international investors when the debt is denominated in domestic currency than when the debt is denominated in foreign currency.

Chapter 1

Sovereign Default Risk and State-Dependent Twin Deficits

1.1 Introduction

The notion of 'twin deficits' is based on the observation that the fiscal deficit and the current account deficit increased in tandem during the 1980s in the U.S. economy. In several European countries twin deficits also occurred in the years before and during the global financial crisis, reviving the debate about whether increasing fiscal deficits cause larger current account imbalances. In particular southern European countries have experienced large increases in current account imbalances and widening fiscal deficits. Since 2008-09 current accounts in these countries are rebalancing despite protracted fiscal deficits, suggesting that the link between the twin deficits diminished. Fiscal deficits were partially the result of large fiscal stimulus packages that were intended to foster economic growth. These large fiscal deficits increased public debt stocks and brought several European governments to the brink of default. Greece defaulted in 2012. In light of the European sovereign debt crisis, we examine whether public indebtedness affects the co-movement of the fiscal balance and the current account. First, we provide empirical evidence showing that the co-movement of the two balances depends on the government debt-to-GDP ratio. Second, we examine whether a small open economy model with the possibility of sovereign default can explain our empirical evidence.

In the first part of the analysis we estimate the government debt-to-GDP threshold to separate our sample into a low and a high debt regime. For that purpose we estimate a dynamic panel threshold model for 15 European countries to quantify the influence of sovereign indebtedness on the relationship between the fiscal balance and the current account.[1] One advantage of the dynamic panel estimation procedure is that we estimate the threshold rather than exogenously imposing it. Based on our estimation strategy we find that the government debt-to-GDP threshold is 72 percent. Splitting our sample into observations below and above the estimated threshold, we find that the correlation of the two balances falls by 0.19 when moving from the low government debt regime to the high government debt regime. In the second part of our analysis we provide a theoretical explanation for the empirical evidence. We allow for the possibility of sovereign default in a non-linear small open economy model. High government debt-to-GDP ratios lead to increasing risk premia as observed in troubled European countries. Facing higher uncertainty about future taxes, households increase saving rather than accumulate debt to smooth consumption during an economic downturn. Private saving increases while fiscal deficits are expanding, leading to a less pronounced current account deficit. The model-based correlation of the fiscal balance and the current account declines by 0.15 when moving from a low government debt regime to a high government debt regime, which is in line with our empirical evidence.

From a theoretical point of view the relationship between the fiscal balance and the current account is ambiguous. The national income accounting identity states that the current account equals the flow of national savings of the private and the public sector net of investment. A fiscal deficit (i.e. negative public saving) leads, ceteris paribus, to a lower current account. Therefore the accounting identity implies a perfect, positive correlation of the twin deficits. However, given fixed investment, the endogenous private saving decision also affects the current account and thus the relationship between the twin deficits. Households internalize the government budget constraint and increase private saving as they expect that higher government debt leads to higher future taxes – a point emphasized by proponents of the Ricardian equivalence. If household saving increases sufficiently, it is possible that the current account remains unaffected implying no co-movement of fiscal deficits and current account deficits.

[1] Our baseline empirical specification follows Nickel and Vansteenkiste (2008) who estimate a dynamic threshold model employing non-dynamic panel techniques based on Hansen (1999). We apply the recently developed methodology of Kremer, Bick, and Nautz (2013) that allows for the estimation of a dynamic panel threshold model, correcting for the potential bias from using an endogenous regressor.

In our theoretical model we try to account for a key feature of the recent European debt crisis, which is the possibility of sovereign default. We assume that the government borrows from international investors and partially defaults when the amount of government debt exceeds the fiscal limit. Following Bi (2012) the fiscal limit is the maximum debt repayment capacity of the government, i.e. the present discounted value of all possible future fiscal surpluses. International investors demand non-linear sovereign default risk premia when public debt approaches unsustainable levels. Labor taxes increase with the public debt stock. Optimizing households receive transfers from the government and they consume, work and trade assets on international financial markets.

The model is calibrated to match data for Greece, which is one of the countries that experienced large external imbalances and high sovereign spreads in recent years. A negative productivity shock at low government debt-to-GDP ratios leads to an increase in taxes and the fiscal balance temporarily moves into deficit. Households increase borrowing to smooth consumption. This implies a strong, positive correlation between the fiscal balance and the current account. A negative productivity shock at high government debt levels affects households via expected labor taxes: First, emerging sovereign risk premia destabilize the fiscal balance, triggering government debt accumulation and increasing expected labor taxes. Second, a government default reduces public debt and expected taxes. As a consequence households expect a larger dispersion of tax rates as government debt approaches high levels. These effects induce optimizing households to increase their saving, which partially offsets current account deficits that result from increasing fiscal deficits. Based on non-linear model simulations with productivity shocks and transfer spending shocks at a low and at a high government debt-to-GDP ratio we show that the correlation of the twins changes by a comparable magnitude as in our empirical analysis.

Current account imbalances and their co-movement with fiscal deficits have received much attention in the literature. The first intertemporal current account model is studied in Sachs (1981) and is extended by Obstfeld and Rogoff (1995). Building on these theoretical foundations, the studies of Glick and Rogoff (1995), Corsetti and Müller (2008) and Bussière, Fratzscher, and Müller (2010) provide evidence that productivity shocks are the main driver of current account dynamics. Corsetti and Müller (2006) show that further important drivers of the co-movement of the twin deficits are the persistence of government spending and the openness of the economy.

Most empirical studies using panel methods (e.g. Chinn and Prasad, 2003; Chinn and Ito, 2007; Gruber and Kamin, 2007; Lane and Milesi-Ferretti, 2012) find a significant positive relationship in the medium-term between the fiscal balance and the current account.[2] This chapter contributes new estimates using the estimation strategy outlined in Kremer et al. (2013). We find a positive and significant coefficient for the fiscal balance below the government debt threshold, but above the threshold the estimate is slightly negative and insignificant. Our estimated threshold of 72 percent is robust to alternative specifications of the empirical model.[3]

In closed economy frameworks Sutherland (1997) and Perotti (1999) show that the consumption response of the private sector can depend on the government debt-to-GDP ratio. In these models a fiscal deficit leads to an increase in consumption at low debt levels, while a fiscal deficit leads to a decrease in consumption at high debt levels. In difference to our framework these models do not allow for a government default.

Increasing government debt-to-GDP ratios have received much attention in the recent policy debate and the academic literature in the course of the European sovereign debt crisis. This work provides a theoretical framework that includes key features of the recent crisis and shows that optimizing households internalize growing government debt stocks, which leads to state-dependent dynamics.

This chapter is structured as follows. Section 1.2 reports our empirical results. Section 1.3 outlines our theoretical model, derives the state-dependent fiscal limit and discusses the non-linear solution method. Section 1.4 presents model simulations which demonstrate that the co-movement of the twins is state-dependent and Section 1.5 concludes.

1.2 Empirical evidence

In the first part of our analysis, we provide empirical evidence on the co-movement of the fiscal balance and the current account and how the relationship of the two

[2] A notable exception is Kim and Roubini (2008), who find evidence in favor of a 'twin divergence' rather than a 'twin deficit' for the U.S. based on VAR methods.

[3] Our estimated threshold is slightly higher than the estimate of Baum et al. (2013), who employ a threshold model to examine non-linear effects of debt and real GDP growth rates.

balances changes at different government debt-to-GDP ratios. Building on Nickel and Vansteenkiste (2008) who estimate a similar dynamic panel threshold model with non-dynamic panel methods, we apply the methodology of Kremer et al. (2013) to avoid a possible endogeneity bias. Following this procedure we estimate the government debt-to-GDP threshold. We show that the correlation of the fiscal balance and the current account for the low and the high government debt regime are significantly different from each other.

1.2.1 Estimation strategy

We apply the following dynamic panel threshold model to estimate the relationship of the fiscal balance and the current account depending on the government debt-to-GDP ratio:

$$\begin{aligned} CA_{it} &= \mu_i + \chi CA_{i,t-1} \\ &+ \beta_1 FB_{it} I(\tfrac{Debt_{it}}{GDP_{it}} \leq \boldsymbol{\gamma}) + \beta_2 FB_{it} I(\tfrac{Debt_{it}}{GDP_{it}} > \boldsymbol{\gamma}) + \alpha' x_{it} + u_{it}, \end{aligned} \tag{1.2.1}$$

where the current account (CA) and the fiscal balance (FB) are measured in percent of GDP.[4] The threshold level (γ) splits the threshold variable (the government debt-to-GDP ratio) into two regimes. The set of control variables is denoted by x_{it}. The indicator function $I(\cdot)$ indicates the regime defined by the threshold variable q_{it} and the threshold level γ. The error term u_{it} is independent and identically distributed with mean zero and finite variance. Following previous literature (e.g. Bussière et al., 2006) we include the lagged current account as a regressor in the baseline specification.

As in Caner and Hansen (2004), we first estimate a reduced form regression for the endogenous variable on a set of instruments, in our case higher lags of the dependent variable. We use the predicted values of the lagged dependent variable $\widehat{CA}_{i,t-1}$ to replace $CA_{i,t-1}$. Second, we repeatedly estimate equation (1.2.1) via least squares for all n threshold candidates to obtain the sum of squared residuals $S_n(\gamma)$. The

[4]Following previous literature (e.g. Chinn and Prasad, 2003; Gruber and Kamin, 2007) we assume that the fiscal balance is not endogenous to the current account. It seems unlikely that European policymakers systematically adjust the fiscal balance to changes in the current account.

estimated threshold is selected as the one that minimizes the sum of squared residuals:

$$\hat{\gamma} = \underset{\gamma}{\operatorname{argmin}}\, S_n(\gamma). \tag{1.2.2}$$

The confidence interval for the estimated threshold level $\hat{\gamma}$ according to Caner and Hansen (2004) is given by

$$\hat{\Gamma} = \{\gamma : LR_n(\gamma) \leq C\}, \tag{1.2.3}$$

where C denotes the 95% percentile of the asymptotic distribution of the likelihood ratio statistic $LR_n(\gamma)$. Given the estimate of the threshold $\hat{\gamma}$, the slope coefficients of equation (1.2.1) are estimated using the generalized method of moments (GMM). Further details on the estimation strategy can be found in Appendix 1.B.

1.2.2 Estimation results

The data set is an unbalanced panel of 15 European countries from 1980 to 2010.[5] Table 1.1 provides the main results of our baseline estimation. The series of threshold candidates ranges from 29.2 percent to 101.6 percent of government debt-to-GDP.[6] The threshold estimate of the government debt-to-GDP ratio is 71.8 percent. This threshold value splits the sample into 260 observations below and 93 observations above the threshold. The 95 percent confidence interval of the threshold ranges from 69.4 percent to 75.0 percent.

The estimated coefficients for the fiscal balance differ across the two regimes. The fiscal balance is positively correlated (0.16) with the current account if government debt is below the threshold. However, in the high government debt regime, there is virtually no relationship (-0.04) between the fiscal balance and the current account. Thus, a one percent increase in the fiscal deficit is associated with a current account deterioration of 0.16 percent in the low government debt regime, while the same increase in the fiscal deficit has virtually no influence on the current account in the high government debt regime.

[5]Detailed information about the data set is given in Appendix 1.A.

[6]We follow Hansen (1999) and trim the series of threshold candidates by excluding those that lie in the highest and in the lowest 5% quantile to avoid that the threshold sorts too few observations in one of the regimes.

A number of previous studies (see Chinn and Prasad, 2003; Chinn and Ito, 2007; Gruber and Kamin, 2007; Bussière, Fratzscher, and Müller, 2010; Lane and Milesi-Ferretti, 2012) estimate the relationship of the fiscal balance and the current account without applying a threshold model. These studies find a positive relationship between these two balances ranging from 0.06 to 0.3. Our fiscal balance estimate for the low government debt regime is in line with these previous estimates. The estimated coefficient of the lagged current account is positive (0.59) and highly significant. This estimate reflects the high persistence of current account dynamics and, thus, the importance of estimating a dynamic model of the current account.

Table 1.1: Estimation results

Variable	Coefficient	Std. dev.
Current account ($t-1$)	0.59***	(0.16)
Fiscal balance (Debt/GDP $\leq \hat{\gamma}$)	0.16**	(0.07)
Fiscal balance (Debt/GDP $> \hat{\gamma}$)	-0.04	(0.05)
Terms of trade	0.05***	(0.02)
Openness	-0.01	(0.01)
Relative income to U.S.	0.01	(0.04)
Output gap (in % of potential GDP)	-0.28***	(0.11)
Change of total investment (in % of GDP)	-0.14	(0.08)
Labor productivity	0.04	(0.03)
Real effective exchange rate	-0.06***	(0.02)
Dependency ratio (% of working-age pop.)	0.16**	(0.08)
Threshold estimate (in % of GDP)	$\hat{\gamma} = 71.8$	
95% confidence region	$[69.4 - 75.0]$	
Total number of observations	353	

Dependent Variable: Current account (t). */**/*** indicate significance at the 10/5/1 percent level. Standard errors in brackets. The threshold of 71.8% splits the sample into 260 observations below and 93 observations above the threshold. The current account and the fiscal balance are measured in percent of GDP.

The point estimates of the control variables are consistent with previous studies and in line with implications of theoretical open economy models. The estimated threshold of 71.8 percent is robust to a range of alternative specifications of the panel model. A detailed discussion of the results, several robustness checks and a detailed discussion of the related empirical literature can be found in Appendix 1.B.

The estimation yields evidence for significant differences in the regime-dependent fiscal balance coefficients indicating that the co-movement of the fiscal balance and the current account is state-dependent. The estimated regime-dependent coefficients (β_i) are *partial* correlations. In our theoretical analysis (in Section 1.3) we examine the model-implied correlation of the two balances at a low and at a high government debt level. The correlation of the twins implied by the model cannot be directly compared to the estimated *partial* correlations of the panel threshold model. To allow for a comparison of the empirical and theoretical results we report the correlation of the two balances in the data for observations below and above the estimated government debt-to-GDP threshold (see Table 1.2). For observations below the threshold of 71.8 percent the correlation of the fiscal balance and the current account is 0.57, whereas the correlation is 0.38 for observations above the threshold. Therefore, the difference amounts to 0.19. The confidence intervals for the correlations in both debt regimes indicate that these values are significantly different at a 10 percent significance level. The change in the correlation of the two balances is robust to considering the lower (69.4%) and the upper (75.0%) bound of the confidence region.

Table 1.2: Regime-dependent correlations of fiscal balance and current account

Threshold: γ_i	corr(FB,CA) $< \gamma_i$	corr(FB,CA) $> \gamma_i$	Δ corr(FB,CA)
71.8	0.57 [0.50, 0.64]	0.38 [0.26, 0.49]	0.19
69.4	0.58 [0.51, 0.64]	0.35 [0.25, 0.47]	0.22
75.0	0.56 [0.50, 0.63]	0.33 [0.21, 0.46]	0.22

Notes: The left column states the estimated threshold value $\hat{\gamma}$ of 71.8 percent and its confidence bounds of 69.4 and 75.0 percent debt-to-GDP. The second and third column report the correlations of the fiscal balance (FB) and the current account (CA) below and above the threshold value. The 90 percent confidence interval of the correlations is reported in brackets. Δ corr(FB,CA) denotes the difference between the correlation in the low debt regime and the correlation in the high debt regime.

In the backdrop of the current account identity our empirical findings suggest that households' behavior responds differently to fiscal deficits at low government debt-to-GDP ratios compared to high ratios: The higher the government debt-to-GDP ratio, the stronger households compensate a fiscal deficit by saving more and thereby increasingly offset the effect of a fiscal deficit on the current account. This finding is robust to considering the correlations as well as the regime-dependent *partial* correlation estimates. The behavior of households at high government debt-to-GDP ratios is consistent with the implications of the Ricardian equivalence hypothesis. In the next section we examine the occurrence of twin deficits in a structural model to provide a theoretical explanation for the observed change in the correlation of the 'twins'.

1.3 The Model

In our theoretical analysis, we consider a small open economy model with defaultable public debt and private asset holdings that are both held by foreign investors. Households borrow and lend at a time-invariant world interest rate and face portfolio adjustment costs. The government raises distortionary labor taxes, pays transfers to households and invests in unproductive government expenditures. The government can default on its outstanding debt. Risk-neutral foreign investors require an endogenous default risk premium when government debt approaches the 'effective fiscal limit'. Following Bi (2012) the effective fiscal limit is a random draw from the model-implied state-dependent distribution of the fiscal limit. A sovereign default occurs when the government debt stock exceeds the effective fiscal limit.

1.3.1 Households

Consider an economy populated by an infinite number of identical households that choose consumption c_t, leisure L_t, and debt d_t^H to maximize

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u\left(c_t, L_t\right) \ , \tag{1.3.1}$$

where $\beta \in (0,1)$ is the discount factor, subject to the budget constraint

$$c_t = W_t\left(1-\tau_t\right)\left(1-L_t\right) + z_t + d_t^H - (1+r)d_{t-1}^H - \frac{\psi}{2}\left(d_t^H - d^H\right)^2 \ , \tag{1.3.2}$$

and a no-Ponzi scheme condition. The budget constraint includes consumption c_t, wage W_t, labor taxes τ_t, government transfers z_t to the households and operations in international financial markets. Households trade a riskless bond d_t^H (positive values of d_t^H denote debt) at a constant world interest rate r. Following Schmitt-Grohé and Uribe (2003) we assume quadratic portfolio adjustment costs that are weighted by the parameter $\psi > 0$, where d^H denotes the steady state net foreign asset position of households. We set the discount factor β equal to one over the gross world interest rate:

$$\beta(1+r) = 1 \; . \tag{1.3.3}$$

We assume Greenwood, Hercowitz, and Huffman (1988) preferences

$$u(c, L) = \frac{\left(c_t - \chi \frac{(1-L_t)^\omega}{\omega}\right)^{1-\sigma} - 1}{1-\sigma} \; , \tag{1.3.4}$$

where the Frisch elasticity of labor supply is $1/(\omega - 1)$ and $\chi > 0$ determines the relative disutility of labor. The degree of relative risk aversion is measured by $\sigma > 0$. As pointed out by Schmitt-Grohé and Uribe (2003) as well as by Mendoza and Yue (2012), these preferences simplify the supply side of the model and help to explain international business cycle facts.[7] The households' first-order conditions are

$$\left(c_t - \frac{\chi(1-L_t)^\omega}{\omega}\right)^{-\sigma} = \lambda_t \tag{1.3.5}$$

$$1 - L_t = \left[\frac{W_t(1-\tau_t)}{\chi}\right]^{\frac{1}{\omega-1}} \tag{1.3.6}$$

$$\lambda_t \left(1 - \psi(d_t^H - d^H)\right) = \beta(1+r)\mathbb{E}_t\lambda_{t+1} \; , \tag{1.3.7}$$

where λ_t is the Lagrange multiplier of the budget constraint.

1.3.2 Production

The production function of output is linear in labor:

$$y_t = A_t\left(1 - L_t\right) \; . \tag{1.3.8}$$

[7]Greenwood et al. (1988) preferences remove the wealth effect, which helps to avoid counterfactual increases in labor when total factor productivity falls.

The process of total factor productivity (TFP), A_t, follows an AR(1) process:

$$\ln\left(\frac{A_t}{A}\right) = \rho_A \ln\left(\frac{A_{t-1}}{A}\right) + \epsilon_{A,t} \ , \qquad \epsilon_{A,t} \sim \mathcal{N}\left(0, \sigma^2_{\epsilon_A}\right) \ , \tag{1.3.9}$$

where A denotes steady state productivity.

Wages are determined on a competitive labor market. Thus, the wage equals the marginal product of labor which in our case equals TFP:

$$W_t = A_t \ . \tag{1.3.10}$$

1.3.3 Government

The government receives tax revenues $\tau_t W_t (1 - L_t)$ through distortionary labor taxation and issues new public debt b_t at a given price q_t. It finances government spending g_t and transfers z_t. In addition, the government can default on the fraction $\triangle_t$ of its outstanding debt and pays back the remaining debt from last period $b_t^d = (1 - \triangle_t)\, b_{t-1}$. Hence, the government budget constraint is:

$$\tau_t W_t (1 - L_t) + b_t q_t = b_t^d + g_t + z_t \ . \tag{1.3.11}$$

We assume that the tax rate τ_t adjusts linearly to the public debt stock:

$$\tau_t - \tau = \gamma_b \left(b_t^d - b\right) . \tag{1.3.12}$$

Government spending is a stationary process that responds systematically to changes in productivity. The parameter γ_g measures the elasticity of government spending g_t with respect to productivity:

$$\log\left(\frac{g_t}{g}\right) = \gamma_g \log\left(\frac{A_t}{A}\right) \ . \tag{1.3.13}$$

Transfers follow a Markov switching process with a stationary and a non-stationary regime as in Davig and Leeper (2011):

$$z_t = \begin{cases} (1-\rho_z)z + \rho_z z_{t-1} + \epsilon_{z,t} & \text{for } S_{Z,t} = 1 \\ \mu z_{t-1} + \epsilon_{z,t} & \text{for } S_{Z,t} = 2 \ , \end{cases} \tag{1.3.14}$$

where $|\rho_z| < 1$, $\mu > 1$ and $\epsilon_{z,t} \sim \mathcal{N}\left(0, \sigma^2_{\epsilon_z}\right)$. Transfers follow a stationary path when $S_{Z,t} = 1$ and an explosive path when $S_{Z,t} = 2$, where the regimes, $S_{Z,t}$, follow a Markov chain with transition matrix

$$\begin{pmatrix} p^{MS} & 1 - p^{MS} \\ 1 - p^{MS} & p^{MS} \end{pmatrix}. \tag{1.3.15}$$

With probability p^{MS} government transfers stay in one of the regimes. For example, in case of a high probability p^{MS} transfers are likely to grow for many periods in the non-stationary regime leading to government debt accumulation. The process switches from one regime to the other with probability $1 - p^{MS}$, such that transfers are ultimately stabilized (as $\rho_z < 1$).

1.3.4 Foreign investors

Domestic households and the domestic government borrow and lend from foreign investors. Unlike the households, the government can default on a fraction of its outstanding debt stock. Foreign investors have access to an international credit market where they can borrow or lend unlimited amounts at a constant world interest rate $r > 0$.

Foreign investors act in competitive markets and choose loans b_t in each period to maximize expected profits ϕ_t, taking prices as given. Risk-neutral investors price bonds such that they break even in expected value:

$$\phi_t = -b_t q_t + \mathbb{E}_t \left[\frac{(1 - \Delta_{t+1})}{1 + r} b_t \right] . \tag{1.3.16}$$

Consequently the equilibrium government bond price q_t reflects the risk of default that investors face:

$$q_t = \mathbb{E}_t \left[\frac{(1 - \Delta_{t+1})}{1 + r} \right] . \tag{1.3.17}$$

As international investors are risk neutral and are fully compensated for the default risk they are indifferent between holding household debt and government bonds.

1.3.5 Current account

In our model household and government liabilities are held vis-à-vis the rest of the world. Borrowing and lending of the private sector and the public sector affect the current account as follows:

$$CA_t^{private} = -d_t^H + d_{t-1}^H \ , \qquad (1.3.18)$$

$$CA_t^{public} = -b_t q_t + b_{t-1} q_{t-1} \ . \qquad (1.3.19)$$

The private sector current account equals the change in households' saving. The public current account is identical to the fiscal balance as the entire public debt stock is held abroad. The sum of both sub-balances amounts to the aggregate current account CA_t.[8]

1.3.6 Laffer curve and fiscal limit

The proportional labor tax induces a distortion in the economy as it influences the households' labor decision, which in turn affects government tax revenues. Distortionary labor taxation gives rise to a Laffer curve and, hence, to a revenue-maximizing tax rate. With Greenwood et al. (1988) preferences tax revenues amount to:

$$T_t = \tau_t W_t \left(1 - L_t\right) = \tau_t W_t \left[\frac{W_t(1-\tau_t)}{\chi}\right]^{\frac{1}{\omega-1}} \ . \qquad (1.3.20)$$

The maximum amount of tax revenues, $T_t^{\max}$, is generated at the revenue-maximizing tax rate which is at the peak of the Laffer curve. The revenue-maximizing tax rate, $\tau_t^{\max}$, is derived as follows:

$$\begin{aligned} \frac{\partial T_t}{\partial \tau_t} &= W_t \left[\frac{W_t(1-\tau_t)}{\chi}\right]^{\frac{1}{\omega-1}} + \tau_t W_t \frac{1}{\omega-1} \left[\frac{W_t(1-\tau_t)}{\chi}\right]^{\frac{1}{\omega-1}-1} \left(-\frac{W_t}{\chi}\right) = 0 \\ \Leftrightarrow \quad & \tau_t^{\max} = \frac{\omega-1}{\omega} \ . \end{aligned}$$

Although the revenue-maximizing tax rate only depends on the Frisch elasticity of

[8]Note that positive values of d_t^H and b_t^d mean that households and the government have external liabilities. An increase of d_t^H or b_t^d implies a negative current account.

labor supply, the maximum amount of tax revenues also depends on the state of the economy (in our case TFP).

Next, we use the revenue-maximizing tax rate to derive the fiscal limit which is a state-dependent distribution. Following Bi (2012) the state-dependent fiscal limit $\mathcal{B}^*(A_t, z_t, S_{Z,t})$ is the maximum level of debt that the government is able to service, i.e. the present discounted value of all possible future fiscal surpluses.[9] The fiscal limit depends on the exogenous states A_t, z_t and $S_{Z,t}$ as well as their future realizations ($j \geq 1$) and the parameters of the model:

$$\mathcal{B}^*(A_t, z_t, S_{Z,t}) = \sum_{j=0}^{\infty} \beta^{t+j} \left(T_{t+j}^{\max} - g_{t+j} - z_{t+j} \right) .$$

We derive the fiscal limit from the perspective of risk-neutral foreign investors, who price the bonds, and thus we set the stochastic discount factor to β. To simulate the fiscal limit $\mathcal{B}^*(A_t, z_t, S_{Z,t})$ for given initial conditions $(A_t, z_t, S_{Z,t})$ we randomly draw future shocks A_{t+j}, z_{t+j} and $S_{Z,t+j}$ for $j = 1, 2, .., N$.[10] Based on $m = 1, 2, ..., M$ simulations of $\mathcal{B}_m^*(A_t, z_t, S_{Z,t})$, we approximate the state-dependent fiscal limit $\mathcal{B}^*(A_t, z_t, S_{Z,t})$ by a normal distribution for each state of the economy.

It is often challenging for investors to determine whether a government is actually willing to increase taxes or to cut spending to avoid a default. Possible resistance by the population against austerity measures might also influence political decisions. Hence, international investors face a high degree of uncertainty that surrounds political processes in countries with high government debt-to-GDP ratios when pricing government bonds. In our model the political uncertainty is reflected by randomly drawing an *effective fiscal limit*, which follows a state-dependent distribution. As in Bi (2012) the government defaults when the public debt stock b_{t-1} exceeds the *effective fiscal limit* b_t^*.[11]

Sturzenegger and Zettelmeyer (2008) show that international investors can usually negotiate a repayment of a large share of the original claim after a default. Therefore, we assume that the government does not default on its entire debt stock, but on the

[9] As Bi (2012) we do not consider the expected value of the fiscal limit, but all possible realizations and thus the fiscal limit is a distribution.

[10] We simulate $N = 200$ periods and repeat this calculation $M = 100000$ $(m = 1, 2, ...M)$ times. At longer horizons the discounted value of government fiscal surpluses is virtually zero.

[11] In contrast, Eaton and Gersovitz (1981) and Arellano (2008) provide a model of sovereign default where the government has an incentive to default despite being able to repay its debt.

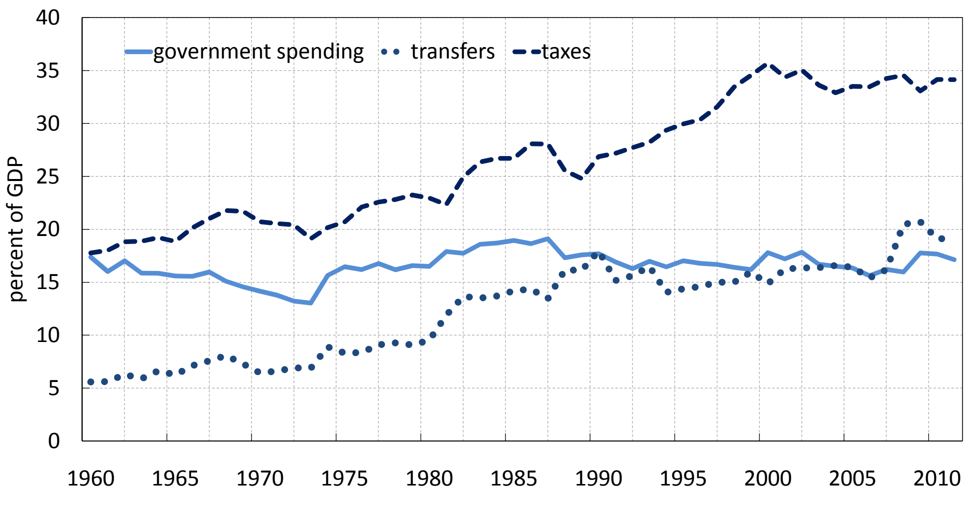
fraction $\delta \in [0, 1]$ which reflects the size of the 'haircut'. Hence, the default scheme is:

$$\Delta_t = \begin{cases} 0 & \text{if } b_{t-1} < b_t^* \sim \mathcal{B}^*(A_t, z_t, S_{Z,t}) \\ \delta & \text{if } b_{t-1} \geq b_t^* \sim \mathcal{B}^*(A_t, z_t, S_{Z,t}) \;. \end{cases} \tag{1.3.21}$$

1.3.7 Calibration

We calibrate the model to match annual data for Greece from 1960 to 2010. The case of Greece is particularly interesting for our analysis as the country currently has the highest debt stock in Europe, experiences surging sovereign interest rates and has large external imbalances.[12] Table 1.3 summarizes the calibration of the model. In line with previous literature we pick conventional values for the discount factor, the coefficient of relative risk aversion, the Frisch elasticity and the disutility of labor. Portfolio adjustment costs are chosen to match the standard deviation of the trade balance to output ratio following Schmitt-Grohé and Uribe (2003). The steady state level of TFP is normalized to 1.

Figure 1.1: Government spending, transfers and taxes in Greece



Source: OECD Economic Outlook No. 86 (2009).

[12]State-dependent twin deficits would also occur when calibrating the model to another country with a different fiscal limit as households saving increases in the proximity of the respective fiscal limit.

Figure 1.1 shows that the ratio of government spending relative to GDP in Greece remained stable over the last decades. Average government spending is 16.57 percent of GDP and average lump-sum transfers amount to 12.27 percent of GDP. The elasticity of government spending with respect to real GDP per worker, γ_g, is estimated in a linear regression for the full sample. The estimation yields a value of -0.07. The estimated response of taxes to an increase of the debt-to-GDP ratio is 0.42 in a linear regression. The government therefore raises taxes by about 1 percentage point in response to an increase of government debt by 2.5 percent of GDP.

Table 1.3: Model calibration to Greek economy

Parameter		Value	Target/Source
Discount factor	β	0.95	Annual interest rate: 5.26%
Relative risk aversion	σ	2	Schmitt-Grohé and Uribe (2003)
Frisch elasticity	$1/(1-\omega)$	0.9	Kimball and Shapiro (2008)
Disutility of labor	χ	3.173	Steady state labor supply: 25%
Portfolio adj. costs	Ψ	0.005	Std(trade balance/GDP): 7.3%
Steady state TFP	A	1	TFP normalized to one
Gov. spending/GDP	g/y	16.57%	OECD EO No. 86 (2009)
Transfer/GDP	z/y	12.27%	OECD EO No. 86 (2009)
Gov. spending elasticity	γ_g	-0.07	Own estimate
Tax reaction coefficient	γ_b	0.42	Own estimate
Government debt/GDP	b/y	60%	Bank of Greece (2013)
Household debt/GDP	d^H/y	60%	Avg. external priv. debt/GDP
Tax rate	τ	31.84%	Avg. government debt/GDP
Default rate	δ	15%	Bi (2012), EU Commission
Productivity persistence	ρ_A	0.53	Own estimate
Std. dev. of prod. shock	σ_{ϵ_A}	0.027	Own estimate
Transfer persistence	ρ_z	0.9	Bi et al. (2013)
Expl. transfer growth	μ	1.01	Bi et al. (2013)
Markov switching prob.	p^{MS}	0.9	Bi et al. (2013)
Std. dev. transfer shock	σ_{ϵ_z}	0.07	Own estimate
	Average fiscal limit:		
Mean (% of GDP)	$\mathcal{B}^*$	156%	MCMC simulation
Std. dev. (% of GDP)	$\sigma_{\mathcal{B}^*}$	21%	MCMC simulation

We set the steady state of total external debt-to-GDP ratio to 120 percent to match average total external liabilities of Greece from 1995 to 2010. About half of total gross external debt are public sector liabilities.[13] Thus, in our calibration, half of total external debt is public external debt and the other half is private sector external debt. As total external liabilities are 120 percent of GDP, we set both the private and public external debt-to-GDP ratio to 60 percent of GDP. To match the average government debt-to-GDP ratio of 60 percent we set the steady state tax rate to 31.84 percent.

We consider various sources to calibrate the size of the haircut in our model for the case of Greece. The European Commission (2011) forecast in autumn 2011 published before the debt restructuring in 2012 reports a government debt-to-GDP ratio of 198.3 percent at the end of 2012. The most recent forecast release in spring 2013 of the European Commission (2013) for the government debt-to-GDP ratio after the debt restructuring is 161.6 percent, suggesting that the haircut is estimated to effectively lower public debt by 18 percent at the end of 2012. Considering the empirical evidence of previous debt restructurings, Bi (2012) computes historical haircuts indicating an average size of 13 percent (excluding default events below a haircut of 3 percent). A haircut of this size is also in line with estimates in Sturzenegger and Zettelmeyer (2008), Panizza (2008) and Moody's (2011). Therefore, we choose a conservative value of 15 percent for the default fraction.[14]

We estimate the exogenous processes for productivity and transfers using HP-filtered data. The log of productivity as measured by real GDP per worker has a persistence of 0.53 and a standard deviation of 0.027 of the shock. Figure 1.1 illustrates that transfer payments from the government to households continuously increased in Greece over the last decades. Following Bi, Leeper, and Leith (2013) we set the Markov switching probability p^{MS} of the transfer process to 0.9. This implies that on average the transfer process stays in each regime for ten years. The parameter of the explosive transfer growth μ is set to 1.01 to match the growth of transfers in Greece since 1960 and ρ_z is set to 0.9. The estimated standard deviation

[13]Based on data from the Bank of Greece 56 percent of total external debt is government debt. To our knowledge disaggregated data for the pre-1995 period is not available.

[14]In March 2012 Greece implemented a 53.5 percent haircut to the nominal value of debt held by the private sector, which roughly held half of the total debt stock suggesting a haircut of around 25 percent. Later in 2012 the Troika (ECB, IMF and European Commission) had to recapitalize the Greek banking system, which was holding around one-third of government debt, effectively reducing the net impact of the debt restructuring. However, assuming a higher default fraction does not alter the mechanism of the model and only changes the maximum risk premia that the international investors demand from the government.

of the transfer shock is 0.07 in a least squares regression.

Based on the calibration we determine the resulting average mean and standard deviation across all fiscal limits. The mean of all fiscal limits is 156 percent of steady state output and the standard deviation is 21 percent as a fraction of steady state GDP. The next section addresses how the fiscal limit changes with the state of the economy.

1.3.8 Laffer curve and fiscal limit for Greece

The revenue maximizing tax rate only depends on the Frisch elasticity. Figure 1.2 shows the Laffer curve for three different values of the Frisch elasticity. Based on the calibration of our model the revenue-maximizing tax rate is 52.6 percent. This tax rate is close to the revenue maximizing labor tax rate of about 60 percent for Greece estimated by Trabandt and Uhlig (2011).

Figure 1.2: Sensitivity of Laffer curve to the Frisch elasticity of labor supply

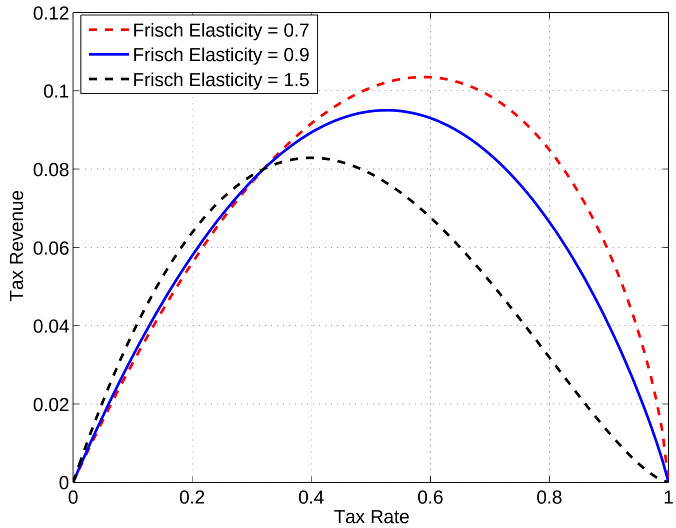
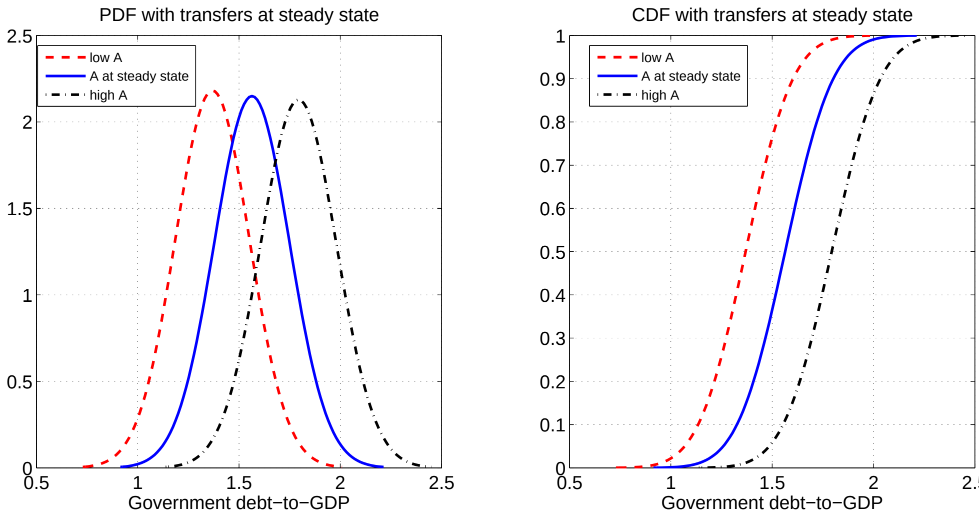


Figure 1.3 displays the distribution of the fiscal limit based on the calibrated model. The fiscal limit depends on the state of the economy.

The left panel depicts the probability density function for different productivity states, while the right panel shows the cumulative density function. As the fiscal limit

Figure 1.3: State-dependent distribution of the fiscal limit



Notes: State-dependent distributions of the fiscal limit for different TFP states and transfers in steady state of the stationary regime. Each distribution is approximated by a normal distribution. The left panel shows the probability density functions and the right panel shows the cumulative density functions.

shifts with the state of the economy, the default probability is also state-dependent. In a recession, i.e. in a low productivity state, the average fiscal limit is much lower compared to an economy that is in a high productivity state. During an economic downturn tax revenues are smaller and productivity is likely to stay at low levels due to its persistence. These two effects lower average future fiscal surpluses, shifting the mean of the fiscal limit to lower government debt-to-GDP ratios. The mean of the fiscal limit is at 163 percent of GDP for an intermediate TFP state, 146 percent of GDP for the lowest TFP state and 183 percent of GDP for the highest TFP state when transfers are at the mean and in the stationary regime.[15] For low TFP states sovereign risk premia occur around 130 percent government debt-to-GDP. This

[15]The fiscal limit also shifts with different states of transfer spending and the Markov switching process between stable and explosive transfer growth. The mean of the fiscal limit is at 140 percent of GDP when transfers are in the highest state and at 189 percent of GDP when transfers are in the lowest state with productivity at steady state and in the stationary transfer regime. A shift from the stable to the explosive transfer regime leads to a shift of the mean of the fiscal limit from 163 percent of debt to GDP to 150 percent of debt to GDP with productivity and transfers at their steady state.

value is close to actual data for Greece as sovereign bond spreads have increased dramatically since April 2010 when government debt-to-GDP was 131 percent. Since 2008 the country is also in a severe recession, which is reflected by a low TFP state in the model.

1.3.9 Solution method

The model features non-linearities due to the possibility of government default and the regime switching of government transfers. For our calibration the fiscal limit is far away from the steady state. For these reasons we use a global solution method to solve the model. The complete set of model equilibrium conditions is listed in Appendix 1.C. We express the model by two first-order difference equations to solve for two policy functions. In particular, the first equilibrium condition is the households' first-order condition (1.3.7) and the second equilibrium condition is the government budget constraint (1.3.11) combined with the first-order condition of foreign investors (1.3.17):

$$\lambda(\Psi_t)\left(1-\psi((f^{d^H}(\Psi_t)-d^H)\right)=\beta\,(1+r)\,\mathbb{E}_t\lambda(\Psi_{t+1}) \tag{1.3.22}$$

$$\frac{b_t^d+g_t+z_t-\tau(\Psi_t)A_t(1-L(\Psi_t))}{f^b(\Psi_t)}=\mathbb{E}_t\left\{\frac{(1-\Delta(f^b(\Psi_t),f^{d^H}(\Psi_t),A_{t+1},z_{t+1},S_{Z,t+1})}{1+r}\right\} \tag{1.3.23}$$

where $\Psi_t=\left\{b_t^d,d_{t-1}^H,A_t,z_t,S_{Z,t}\right\}$ is the state vector of the economy. To solve the model we employ the non-linear algorithm described in Coleman (1991) and Davig (2004). This procedures discretizes the state space Ψ_t and finds a fixed point in the policy rules $b_t=f^b(\Psi_t)$ and $d_t^H=f^{d^H}(\psi_t)$ for each grid point in the state space. Further details on the solution method are provided in Appendix 1.D.

1.4 Model results

First, we show that the correlation of the fiscal balance and the current account changes with the government debt-to-GDP ratio. Then, we provide intuition for the change of the correlation examining policy rules. Finally, to illustrate the state-dependent model dynamics, we present impulse responses to productivity shocks at a low and at a high government debt-to-GDP ratio.

1.4.1 State-dependence of twin deficits

Table 1.4 presents the correlations between the fiscal balance and the current account at a low and at a high government debt-to-GDP ratio.[16] The correlation of the two balances declines as government debt-to-GDP levels increase, in line with our empirical results in Section 1.2. The model with both shocks implies a perfect correlation of the fiscal balance and the current account for public debt-to-GDP at 60 percent. The correlation of the twins declines to 0.85 at a government debt-to-GDP ratio of 140 percent. Therefore the change in the correlation is 0.15 when moving from the low government debt regime to the high debt regime. At low government debt levels government and household debt co-move almost one-for-one ($corr(CA^{private}, FB) = 0.99$). However, at high government debt-to-GDP levels the correlation is much lower ($corr(CA^{private}, FB) = 0.04$).

To compare our model-implied correlation with actual data we report the change of the state-dependent correlation of the fiscal balance and the current account calculated in Section 1.2 for 15 European countries. Table 1.4 reports the absolute change (0.19) in the correlations of the twins between the high and low government debt regime in the data. The model-implied change in the correlation (0.15) is close to the one found in the data.

To shed light on the relative importance of each shock Table 1.4 also reports the model-implied correlations conditional on each shock. Even though the correlation of the fiscal balance and the current account conditional on transfer shocks is high (0.86) in the low debt regime, it is negative (-0.36) in the high debt regime. In line with Corsetti and Müller (2008) we find that the unconditional correlation of the two balances in the model is dominated by TFP shocks.

1.4.2 Model dynamics

To highlight the key transmission mechanisms we discuss the properties of two policy functions: sovereign interest rates and households' saving. International investors demand risk premia when government debt approaches the fiscal limit and

[16] The reported statistics for the model are an average over 500 simulations of eight years each. We only include simulations without default episodes as a default implies a large current account surplus. We choose a short simulation period to avoid a possible bias in the reported results by excluding too many draws that result in a government default.

Table 1.4: State-dependent correlations of fiscal balance and current account

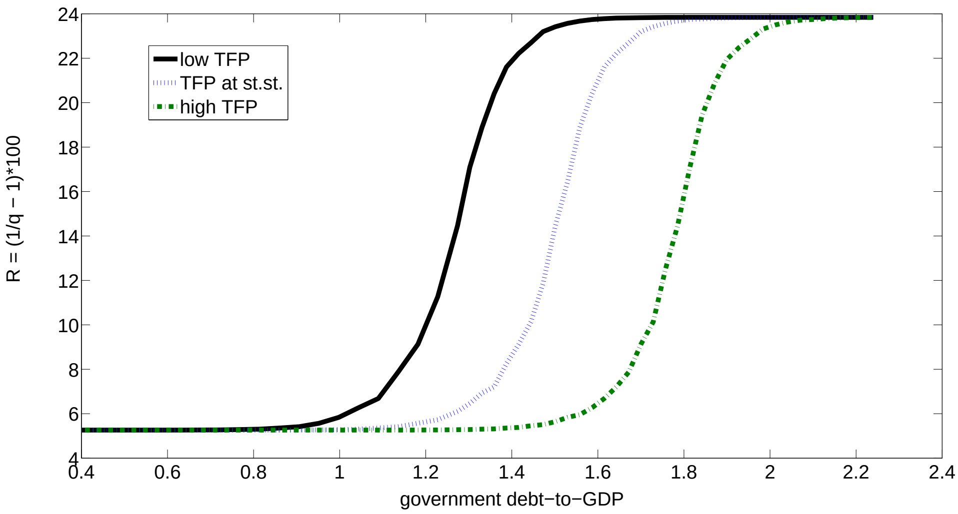
Low vs. high government debt-to-GDP: Δ corr(FB,CA)	
Data	0.19
Model	0.15
Low government debt-to-GDP at 60 percent: corr(FB,CA)	
Both shocks	1.00
TFP shocks	1.00
Transfer shocks	0.86
High government debt-to-GDP at 140 percent: corr(FB,CA)	
Both shocks	0.85
TFP shocks	0.86
Transfer shocks	-0.36

Notes: Correlations of fiscal balance (FB) and current account (CA), both in percent of GDP. The low government debt level is the steady state value of the model. Δ corr(FB,CA) denotes the difference between the correlation of the low debt regime and the correlation of the high debt regime. All simulations are based on the stationary transfer regime.

the probability of default increases (see Figure 1.4). Up to a government debt-to-GDP ratio of around 100 percent foreign investors do not demand sovereign default risk premia as they expect no risk of a government default in the next period independent of today's productivity state. Hence, sovereign bond yields equal the risk-free rate. Sovereign interest rates increase up to 24 percent for high government debt levels. Since international investors are risk neutral they demand risk premia that offset the expected loss due to the possible government default.

The government debt level at which investors demand risk premia depends on the state of the economy as the latter affects the fiscal limit. For example, if the economy is in a recession, i.e. in a low TFP state, tax revenues are low and the fiscal limit is shifted to the left. Hence, during a recession the probability of sovereign default is much higher than during an economic boom. Consequently, at the lowest productivity state default risk premia begin to emerge at around 100 percent of government debt-to-GDP, whereas at the highest TFP state risk premia emerge at around 160 percent of government debt-to-GDP.

Figure 1.4: Sovereign interest rates at different government debt-to-GDP ratios

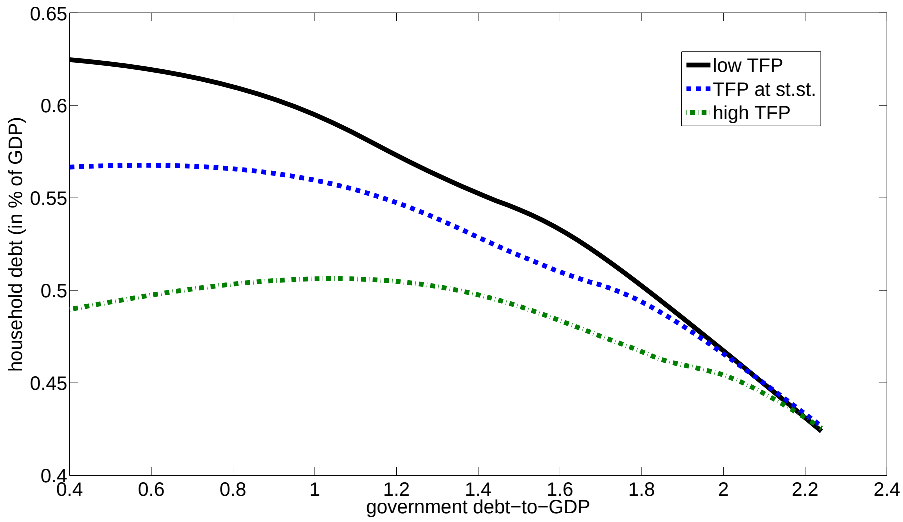


Notes: Household debt and transfer spending are both set to steady state and transfer spending is in the stationary regime. Horizontal axis: ratio of government debt-to-GDP. Vertical axis: in percentage points.

Households trade assets with foreign investors to smooth consumption and to insure against expected tax changes that result from the risk of government default. The saving decision at different productivity states depends non-linearly on the public debt stock (see Figure 1.5). When government debt-to-GDP is around 60 percent (steady state) households accumulate debt relative to steady state household debt to smooth consumption at a low TFP state. However, around 140 percent government debt-to-GDP ratio households save relative to steady state household debt in all TFP states as public debt increases.

The households' saving decision is influenced by the level of government debt due to the possibility of government default in the proximity of the fiscal limit. A more costly roll-over of government debt increases the fiscal deficit and leads to higher expected future labor taxes. However, households benefit from a realized government default as a default leads to lower government debt and, thus, to lower distortionary taxes.[17] The distortion caused by labor taxes increases with higher government debt levels. To insure against higher expected future labor taxes households save relative to steady state household debt when government debt is high even when faced with negative TFP shocks.

Figure 1.5: Households' saving decision at different government debt-to-GDP ratios



Notes: Transfer spending is at steady state and in the stable process. Horizontal axis: ratio of government debt-to-GDP. Vertical axis: households' choice of debt in percent of GDP when the households' debt stock in the last period is at steady state.

1.4.3 Impulse response functions

We simulate the model conditional on a negative productivity shock at different government debt-to-GDP ratios to assess the state-dependent dynamics. A negative TFP shock captures the economic downturn of Greece which is in a recession since 2008. The shock destabilizes the fiscal sector leading to sovereign interest rate spreads at high public debt levels.

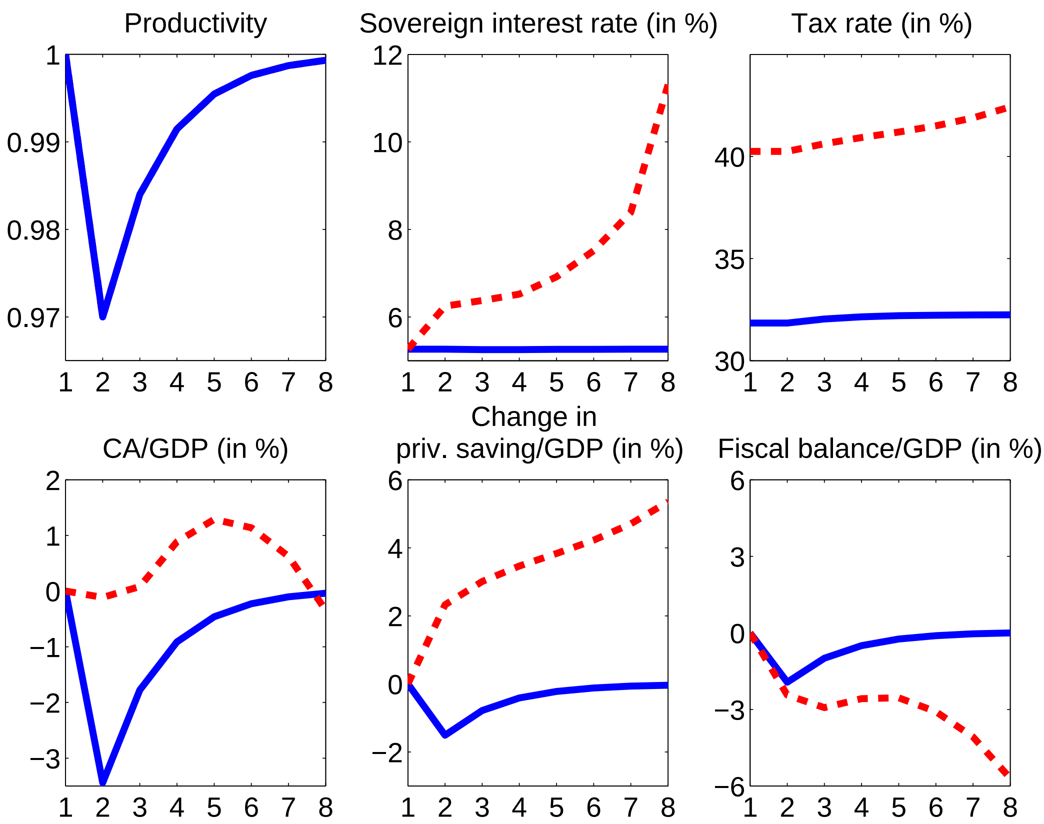
[17] Introducing an exogenous cost of default as in Arellano (2008) would lead to a stronger increase of household saving at high government debt as households would try to insure against this cost. This would lead to a stronger reduction of the correlation of the twins.

Figure 1.6 displays the effects of a negative TFP shock at a low (60%) and a high (140%) government debt-to-GDP ratio. At a low government debt-to-GDP ratio the negative productivity shock causes labor and tax revenues to decline, government spending to increase and the fiscal balance turns negative. Higher tax rates and lower output leads households to increase debt to smooth consumption. Households therefore increase private debt, i.e. the change in private saving is negative. Hence, the change in private saving and the fiscal balance co-move positively and the aggregate current account turns negative. Thus, the correlation of the fiscal balance and the current account is unity.

At high government debt levels a negative productivity shock of the same size again leads to a negative fiscal balance. Growing government debt brings the stock of sovereign debt close to the fiscal limit, leading to a surge of sovereign risk premia. Households increase saving as they expect that further increases of government debt and tax rates are very likely and the dispersion of tax rates increases. The change in private saving therefore turns positive and outweighs the negative contribution of the fiscal balance such that the current account moves into surplus. Due to the endogenous reaction of household saving, the correlation between the fiscal balance and the current account is much lower at high government debt-to-GDP than at a low ratio. In addition, the simulation reflects a situation where increasing risk premia destabilize the government debt-to-GDP ratio as observed during the current European sovereign debt crisis. Without a strong reduction of government expenditures or higher tax revenues the government debt stock is not sustainable resulting in a default in accordance with the actual debt restructuring of Greece in 2012.

In line with the empirical results our model provides an explanation for the decline in the correlation of the fiscal balance and the current account as the government debt-to-GDP ratio increases. In the model the households' optimal saving decision changes with the government debt-to-GDP ratio which explains the change of the correlation. In particular, as illustrated by the impulse responses to a negative TFP shock, private saving increases at high government debt, but falls at low government debt-to-GDP ratios. Hence, the correlation of the 'twins' is state-dependent and at high government debt households' saving behavior alleviates the fall in the current

Figure 1.6: Simulation of negative TFP shock at low vs. high government debt



Notes: Impulse responses to a 3 percent negative productivity shock. We initialize the simulation at 60% government debt-to-GDP (blue solid line) and 140% government debt-to-GDP (red dashed line). Household debt is set to its ergodic mean. A time unit is one year.

account. The change in the model-based correlation of the fiscal balance and the current account is 0.15, which is in line with the change in the empirical correlation of the twins.

1.5 Conclusion

In the first part of this chapter, we estimate a government debt-to-GDP threshold based on a dynamic panel threshold model following Kremer et al. (2013) for a sample of 15 European countries. One advantage of the dynamic panel estimation procedure is that we estimate the threshold rather than exogenously imposing it. We contribute to the twin deficits debate by showing that the correlation of the fiscal balance and the current account depends on the government debt-to-GDP ratio. Based on the estimated threshold of 72 percent we distinguish between a low and a high government debt regime. For each regime we calculate the correlation of the fiscal balance and the current account and find that the state-dependent correlation falls by 0.19 when moving from observations below the threshold to those that are above the threshold.

In the second part of this chapter, we examine a small open economy model allowing for sovereign default to show that the correlation of the twin deficits depends on the level of government debt in line with the observed empirical findings. At high government debt-to-GDP ratios the looming sovereign default risk increases sovereign interest rates, which deteriorate the fiscal balance. Rising sovereign debt levels lead to higher labor taxes, inducing households to increase saving. Also, precautionary saving increases as the dispersion of future expected taxes rises the closer the government debt stock moves to the fiscal limit. Non-linear model simulations reveal that the households' saving channel partially offsets fiscal deficits at high government debt-to-GDP ratios, inducing a decline in the correlation of the fiscal balance and the current account. The decline in the correlation of 0.15 is close to the change of the correlation in the empirical analysis.

The results of this chapter suggest that households' saving has an offsetting effect on substantial and persistent fiscal deficits due to high sovereign risk premia. At high government debt-to-GDP ratios households save more than at times when the economy has a low government debt-to-GDP ratio. Therefore, our evidence — in line with recent data for southern European countries — points to a potential rebalancing of the current account as households increase saving, because of large fiscal deficits that prevail due to high borrowing costs.

The recent global financial crisis and the European sovereign debt crisis with their severe macroeconomic effects have shown that state-dependent dynamics can be important. Areas in which state-dependent dynamics are likely to play a crucial role are, for example, the size of fiscal multipliers and the effectiveness of austerity programs. This chapter reveals another example of state-dependence and shows that the size of the government debt-to-GDP ratio affects the co-movement of the fiscal balance and the current account.

Appendix to Chapter 1

1.A Data description

Table 1.5: List of variables and definitions

Variable	Source	Description
Current account	IMF WEO	Current account balance (in % of GDP)
Fiscal balance	IMF WEO	Fiscal balance (in % of GDP). Net lending is calculated as revenue minus total expenditure.
Government debt	IMF WEO	Government debt (in % of GDP). Gross debt consists of all liabilities that require payment or payments of interest and/or principal by the debtor to the creditor.
Terms of trade	IMF IFS	Export price index divided by import price index
Openness	OECD	Absolute value of exports plus absolute value of imports (in % of GDP)
Relative income	IMF WEO	GDP per capita (PPP) relative to U.S. GDP per capita (PPP)
Output gap	IMF WEO	Output gap (in % of potential GDP)
Change of total invest.	IMF WEO	Change of total investment (in % of GDP)
Labor productivity	OECD	Labor productivity of the total economy
REER	BIS	Weighted average of bilateral exchange rates adjusted by relative consumer prices
Dependency ratio	WDI	Age dependency ratio (in % of working-age population)

Data sources: IMF WEO: IMF World Economic Outlook (Oct 2012), IMF IFS: IMF International Financial Statistics (May 2012), OECD: OECD Economic Outlook No. 92 (Dec 2012), BIS: Bank for International Settlements effective exchange rate indices: narrow indices (Jan 2013), World Bank WDI: World Bank Development Indicators (Jan 2013).

Table 1.6: Summary statistics of dataset

Country	T	mean(CA/GDP)	mean(FB/GDP)	mean($Debt/GDP$)
Austria	23	0.46	-2.75	63.1
Belgium	20	3.33	-2.70	109.4
Germany	16	2.47	-2.79	64.5
Denmark	13	2.68	1.24	51.7
Spain	31	-2.95	-3.41	46.6
Finland	31	1.41	1.01	33.9
France	31	0.12	-3.34	48.7
Great Britain	31	-1.41	-3.16	44.5
Greece	23	-6.01	-8.20	97.8
Ireland	31	-1.84	-4.52	68.7
Italy	22	-0.41	-5.83	108.1
The Netherlands	16	5.29	-1.73	58.2
Norway	31	6.31	7.25	41.3
Portugal	16	-4.84	-2.01	61.3
Sweden	18	5.11	-1.06	55.7

Notes: T: Maximum number of time periods available, CA/GDP: Current account in percent of GDP, FB/GDP: Fiscal balance in percent of GDP, $Debt/GDP$: Government debt in percent of GDP.

1.B Empirical estimation

1.B.1 Data

The data set is an unbalanced panel of 15 European countries from 1980 to 2010.[18] We include a broad set of control variables that potentially affect the current account. In particular, along with the fiscal balance the baseline specification includes the terms of trade, openness, relative income to the U.S. economy, output gap (in percent of potential GDP), the change in total investment (in percent of GDP), labor productivity (of the total economy), the real effective exchange rate and the dependency ratio (in percent of working-age population). Detailed information about the data set is given in Appendix 1.A.

1.B.2 Methodology

We estimate a dynamic panel threshold model of the form

$$y_{it} = \mu_i + \chi y_{i,t-1} + \beta_1 z_{it} I(q_{it} \leq \boldsymbol{\gamma}) + \beta_2 z_{it} I(q_{it} > \boldsymbol{\gamma}) + \alpha' x_{it} + u_{it}, \qquad (1.B.1)$$

where subscript $i = 1, ..., N$ represents the country and subscript $t = 1, ..., T$ denotes the time period. y_{it} is the dependent variable, μ_i is the country specific fixed effect and $y_{i,t-1}$ is an endogenous regressor. z_{it} is a vector of explanatory regressors, $I(\cdot)$ is an indicator function indicating the regime defined by the threshold variable q_{it}, and γ is the threshold level. Thus, the impact of z_{it} on y_{it} can potentially vary depending on whether the threshold variable q_{it} is below or above the threshold. The threshold level γ splits the sample into two regimes, allowing for the estimation of the regime-dependent impact of z_{it} as measured by the coefficients β_1 and β_2. Furthermore, x_{it} contains a set of explanatory regressors which are independent of the threshold. The error term u_{it} is independent and identically distributed with mean zero and finite variance.

Our estimation strategy follows Kremer et al. (2013) who overcome several econometric challenges. In particular, they combine the estimation methods of non-dynamic

[18] The sample includes the following countries: Austria, Belgium, Denmark, Finland, France, Germany, Great Britain, Greece, Ireland, Italy, The Netherlands, Norway, Portugal, Spain and Sweden.

panel threshold models in Hansen (1999) with the estimation strategy in Caner and Hansen (2004) that applies to cross-sectional threshold models with endogenous regressors. Hansen (1999) provides a method to estimate threshold effects in non-dynamic panel models where all regressors have to be exogenous. To eliminate the fixed effects mean differencing is applied. However, in a dynamic panel model as considered in equation (1.B.1) mean differencing potentially leads to inconsistent estimates as the lagged dependent variable will always be correlated with the mean of the individual errors and, thus, with all transformed individual errors (see Arellano, 2003, p. 17). Caner and Hansen (2004) develop an estimator and an inference theory for models with endogenous regressors and an exogenous threshold variable. Their theory applies to cross-sectional data and therefore needs to be extended to the estimation of panel data. For the endogenous regressor an instrumental variable estimation is applied. Building on these two papers, Kremer et al. (2013) provide a new, dynamic version of Hansen's panel threshold model. As in Caner and Hansen (2004) their procedure eliminates fixed effects with the forward orthogonal deviations transformation suggested by Arellano and Bover (1995). Subtracting the average of all future available observations of a variable avoids serial correlation of the transformed errors.

For our empirical exercise we apply the dynamic panel threshold model to estimate the relationship of the fiscal balance and the current account depending on the ratio of government debt-to-GDP:

$$\begin{aligned} CA_{it} &= \mu_i + \chi CA_{i,t-1} \\ &+ \beta_1 FB_{it} I(\tfrac{Debt_{it}}{GDP_{it}} \leq \boldsymbol{\gamma}) + \beta_2 FB_{it} I(\tfrac{Debt_{it}}{GDP_{it}} > \boldsymbol{\gamma}) + \alpha' x_{it} + u_{it}, \end{aligned} \tag{1.B.2}$$

where the current account (CA) and the fiscal balance (FB) are measured in percent of GDP. The threshold variable is the ratio of government debt-to-GDP. The set of control variables x_{it} includes the variables described above.

Following previous literature (e.g. Bussière et al., 2006), we include the lagged current account as a regressor in the baseline specification. We instrument for $CA_{i,t-1}$ using lagged variables ($CA_{i,t-3}$, $CA_{i,t-4}$ and $CA_{i,t-5}$). Employing few lags prevents overfitting the predicted variable and reduces a possible bias of the coefficient estimates. However, as there is a trade-off between bias and efficiency in small samples, using only few lags comes at the cost of loosing efficiency. To assess the importance of the number of lags included we repeat the estimation using all of the available lags and find that the results are very close to the baseline results (see Appendix 1.B.6).

1.B.3 Further empirical results

The first column of Table 1.7 reports the results of our baseline specification. The key results are discussed in Section 1.2.2 in the main text.

The terms of trade have a significant, positive coefficient (0.05). An increase in the terms of trade reflects that the prices of the export goods increase relative to the prices of the import goods. The positive coefficient is consistent with a positive relationship between national savings and a terms of trade improvement. The partial correlation of openness (defined as imports plus exports in percent of GDP) with the current account is very small and insignificant (-0.01). The estimated coefficient of the relative income to the U.S. has a positive sign (0.01) which might reflect higher investment and borrowing in poorer countries due to either a catch-up effect or higher expected future income. The coefficient is, however, insignificant which is not surprising given that the considered countries all have an income level comparable to the one of the U.S. economy. The output gap co-moves negatively (-0.28) with the current account. A country experiencing an economic expansion would therefore, ceteris paribus, experience a deterioration of the current account which indicates that the positive impact of higher saving is overcompensated by higher investment inflows. As expected from the current account identity a change of investment is associated with a decline (-0.14) of the current account. The coefficient for labor productivity is insignificant (0.04), while the coefficient of the real effective exchange rate is negative (-0.06). The significant positive coefficient (0.16) of the dependency ratio could be explained by lower investment in countries which have a larger share of the population out of the labor force.

We also estimate a non-dynamic panel model (see right column of Table 1.7) to compare our results to previous studies. The threshold estimate in the non-dynamic model is slightly higher than in the dynamic model. While we confirm our previous finding that the partial correlation of the fiscal balance and the current account is lower at high government debt levels, we find that both estimated coefficients are larger compared to the estimates of the dynamic model. These results also highlight

Table 1.7: Estimation results

Variable	Dynamic panel	Non-dynamic panel
Current account ($t-1$)	0.59***	
	(0.16)	
Fiscal balance (Debt/GDP $\leq \hat{\gamma}$)	0.16**	0.43***
	(0.07)	(0.06)
Fiscal balance (Debt/GDP $> \hat{\gamma}$)	-0.04	-0.01
	(0.05)	(0.06)
Terms of trade	0.05***	0.09***
	(0.02)	(0.02)
Openness	-0.01	-0.01
	(0.01)	(0.02)
Relative income to U.S.	0.01	0.08
	(0.04)	(0.06)
Output gap	-0.28***	-0.67***
(in % of potential GDP)	(0.11)	(0.07)
Change of total investment	-0.14	0.12
(in % of GDP)	(0.08)	(0.08)
Labor productivity	0.04	0.09***
	(0.03)	(0.03)
Real effective exchange rate	-0.06***	-0.10***
	(0.02)	(0.02)
Dependency ratio	0.16**	0.37***
(% of working-age pop.)	(0.08)	(0.09)
Threshold estimate (in % of GDP)	$\hat{\gamma} = 71.8$	$\hat{\gamma} = 75.0$
95 % confidence region	[69.4 – 75.0]	[69.4 – 91.05]
Total number of observations	353	353

Dependent Variable: Current account (t). */**/*** indicate significance at the 10/5/1 percent level. Standard errors in brackets. The threshold of 71.8% (75.0%) splits the sample into 260 (271) obs. below and 93 (82) obs. above the threshold. The current account and the fiscal balance are measured in percent of GDP.

the importance of including the lagged current account in our baseline estimation. Compared to the non-dynamic panel the high persistence of the current account and the lower regime-dependent estimates in the dynamic panel model suggest that our baseline specification corrects for a potential bias due to omitting an endogenous regressor.

1.B.4 Robustness

We estimate a range of alternative specifications to confirm and extend our baseline estimation results. First, we estimate the model for the period 1980 to 2007, excluding the period from 2008 to 2010. The financial crisis with its strong influence on average debt levels, fiscal balances and current accounts could potentially affect our estimation results. Second, we re-estimate the model excluding countries with very high or low government debt-to-GDP ratios.

Excluding the financial crisis period we estimate the same government debt-to-GDP threshold of 71.8 percent (see first column of Table 1.8). The coefficients for the control variables are close to those of our baseline results. The exclusion of the financial crisis period slightly affects the estimate of the fiscal balance: The estimate below the threshold increases from 0.16 to 0.30 and at the same time becomes statistically more significant. The estimate at a high government debt-to-GDP ratio decreases from -0.04 to -0.21. Thus, the difference between the state-dependent coefficients of the fiscal balance becomes larger when excluding the financial crisis episode. In comparison to the baseline results household saving therefore compensates a fiscal deficit less in the low debt regime. The exclusion of the crisis period confirms our baseline results: households become more Ricardian at high government debt levels, increasingly compensating the impact of fiscal deficits on the current account by higher household saving.

In a second robustness check we exclude the country with the lowest and several countries with a high average government debt-to-GDP ratio from our sample (see Table 1.8). These countries might influence the estimation results as a majority of their observations are assigned to only one of the two debt regimes. Finland is the country with the lowest average government debt-to-GDP ratio, while there are three countries with relatively high average debt-to-GDP ratios: Belgium, Greece and Italy. We exclude one country at a time. Excluding Belgium (the country with the highest average debt-to-GDP ratio) yields the same estimated threshold of 71.8 percent and the exclusion is inconsequential for the estimation results. Excluding Italy or Finland also yields the same estimated thresholds and similar coefficient estimates as in the baseline estimation. The threshold estimate is slightly larger when excluding Greece, but the point estimates are very similar to the results of the complete sample.

Table 1.8: Robustness

Variable	Subperiod 1980-2007	Excluding Belgium	Excluding Italy	Excluding Greece	Excluding Finland
CA $(t-1)$	0.44***	0.56***	0.59***	0.62***	0.50***
	(0.16)	(0.16)	(0.15)	(0.16)	(0.17)
Fiscal balance	0.30***	0.17**	0.20**	0.17**	0.23***
(Debt/GDP $\leq \hat{\gamma}$)	(0.08)	(0.07)	(0.08)	(0.08)	(0.08)
Fiscal balance	-0.21**	-0.03	0.03	-0.01	0.08
(Debt/GDP $> \hat{\gamma}$)	(0.09)	(0.05)	(0.07)	(0.07)	(0.07)
Terms of trade	0.05***	0.05***	0.04***	0.05***	0.05**
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Openness	0.004	0.005	0.001	-0.01	-0.01
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Relative income	-0.01	0.004	-0.01	0.02	0.04
to U.S.	(0.04)	(0.04)	(0.05)	(0.05)	(0.05)
Output gap	-0.49***	-0.30***	-0.32***	-0.27**	-0.38***
(in % of pot. GDP)	(0.12)	(0.11)	(0.11)	(0.11)	(0.12)
Change of total inv.	-0.13	-0.13	-0.17**	-0.17**	-0.20**
(in % of GDP)	(0.11)	(0.09)	(0.07)	(0.08)	(0.09)
Labor productivity	0.07**	0.03	0.04*	0.04	0.05*
	(0.03)	(0.02)	(0.02)	(0.03)	(0.03)
Real effective	-0.07***	-0.06***	-0.04**	-0.05***	-0.04*
exchange rate	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Dependency ratio (in %	0.25***	0.19**	0.22**	0.19**	0.22**
of working-age pop.)	(0.09)	(0.09)	(0.10)	(0.10)	(0.09)
Threshold (% of GDP)	$\hat{\gamma} = 71.8$	$\hat{\gamma} = 71.8$	$\hat{\gamma} = 71.8$	$\hat{\gamma} = 86.9$	$\hat{\gamma} = 71.8$
95 % confidence region	[69.4-74.1]	[69.4-75.0]	[69.4-75.0]	[82.3-91.05]	[69.4-88.0]
Total number of obs.	308	333	331	330	322

Dependent Variable: Current account (t). */**/*** indicate significance at the 10/5/1 percent level. Standard errors in brackets. The current account and the fiscal balance are measured in percent of GDP.

1.B.5 Discussion of related empirical literature

A number of papers estimate the medium-term relationship between the fiscal balance and the current account estimating panel models without threshold. Chinn and Prasad (2003) estimate a static panel for a large set of 88 countries for the sample ranging from 1971 to 1995 and find a significant point estimate for the fiscal balance coefficient of 0.3. Chinn and Ito (2007) report a point estimate of around 0.15 for both a sample of 89 countries as well as for a sub-sample of industrialized countries from 1971 to 2004. Gruber and Kamin (2007) report a value of 0.11 using a longer time span but fewer countries (61) than Chinn and Prasad (2003). The panel estimation of 21 OECD countries in Bussière et al. (2010) yields a significant, positive point estimate of 0.14. Bussière et al. (2006) employ various estimators (LSDV, IV and GMM) to a dynamic panel and find a positive relationship between the fiscal balance and the current account ranging from 0.06 to 0.25. The estimation is based on data for 21 OECD countries for a sample from 1980 to 2003. Their paper also finds a highly significant coefficient for the lagged current account. Lane and Milesi-Ferretti (2012) estimate a static panel for 65 economies for a large sample ranging from 1969 to 2008 finding a highly significant positive fiscal balance coefficient of 0.24. Based on these studies there exists compelling evidence for a small, positive relationship of the fiscal balance and the current account. Studies that estimate a dynamic model find a high persistence of the lagged current account comparable to our estimation results. Estimating our dynamic panel model without a threshold we also find that there is a positive relationship between the current account and the fiscal balance.

In a related study Röhn (2010) finds for a panel of 16 OECD countries that increasing private saving offsets a deficit financed rise in public spending to a larger extend the higher the level of public debt. This implies that consumers become more Ricardian with growing levels of public debt. The findings of Röhn (2010) are consistent with the fact that the correlation of the fiscal balance and the current account declines with rising government debt levels as increasing household saving offsets the negative effect of government deficits on the current account at high public debt levels.

Our results corroborate those of Nickel and Vansteenkiste (2008) who find that the relationship between the fiscal balance and the current account depends on the government debt-to-GDP ratio. Using a sample of eleven Euro area countries for the years 1981 to 2005 they obtain a significant positive coefficient of 0.36 for the estimate of the fiscal balance for the lowest debt regime. For the highest debt regime the estimate is -0.61 but it is not statistically different from zero. They also estimate a sample of 22 industrialized countries and obtain an estimate for the fiscal balance coefficient of 0.45 (significant) and -0.11 (not significant) for the lowest and highest debt regime, respectively. In difference to the estimation strategy used in our study, the results of Nickel and Vansteenkiste (2008) are based on the estimation and inference theory for non-dynamic panels by Hansen (1999).[19] Due to the high persistence of the current account the estimates of Nickel and Vansteenkiste (2008) are potentially biased. Applying the dynamic version of Hansen's model proposed by Kremer et al. (2013), we avoid a potential bias. We obtain consistent estimates that are smaller than those of Nickel and Vansteenkiste (2008), but we confirm the regime-dependent influence of government debt-to-GDP ratios on the correlation of the fiscal balance and the current account.

[19]These authors use a different sample of countries and analyze a shorter time span.

1.B.6 Additional estimation results

Table 1.9: Estimation results using all available lags

Variable	Coefficient	Std. Error
Current account ($t-1$)	0.56***	(0.09)
Fiscal balance (Debt/GDP $\leq$ 71.8%)	0.17***	(0.05)
Fiscal balance (Debt/GDP > 71.8%)	-0.04	(0.04)
Terms of trade	0.05***	(0.01)
Openness	−0.01	(0.01)
Relative income to U.S.	0.01	(0.04)
Output gap (in % of potential GDP)	−0.30***	(0.07)
Change of total investment (in % of GDP)	−0.12*	(0.07)
Labor productivity	0.04*	(0.02)
Real effective exchange rate	−0.06***	(0.02)
Dependency ratio (% of working-age pop.)	0.17**	(0.07)
Threshold estimate (in % of GDP)	$\hat{\gamma} = 71.8$	
99 % confidence region	[69.4 − 88.0]	
Total number of observations	353	

Dependent Variable: Current account (t). */**/*** indicate significance at the 10/5/1 percent level. Standard errors in brackets. The threshold of 71.8% splits the sample into 260 observations below and 93 observations above the threshold. The current account and the fiscal balance are measured in percent of GDP. We use the largest available number of lags for the current account as instruments for the lagged current account.

1.C Non-linear model equilibrium conditions

$$(1 - L_t) = \left[\frac{A_t(1-\tau_t)}{\chi}\right]^{\frac{1}{\omega-1}} \tag{1.C.1}$$

$$\lambda_t = \left(c_t - \frac{\chi(1-L_t)^{\omega}}{\omega}\right)^{-\sigma} \tag{1.C.2}$$

$$\lambda_t\left(1 - \psi(d_t^H - d^H)\right) = \beta(1+r)\mathbb{E}_t(\lambda_{t+1}) \tag{1.C.3}$$

$$c_t + \frac{\psi}{2}\left(d_t^H - d^H\right)^2 = A_t\left(1-\tau_t\right)\left(1-L_t\right) + z_t + d_t^H - (1+r)d_{t-1}^H \tag{1.C.4}$$

$$y_t = A_t\left(1 - L_t\right) \tag{1.C.5}$$

$$\tau_t A_t\left(1 - L_t\right) + b_t q_t = \left(1 - \triangle_t\right) b_{t-1} + g_t + z_t \tag{1.C.6}$$

$$b_t^d = \left(1 - \triangle_t\right) b_{t-1} \tag{1.C.7}$$

$$q_t = \mathbb{E}_t\left[\frac{(1-\Delta_{t+1})}{1+r}\right] \tag{1.C.8}$$

$$T_t = \tau_t A_t\left[\frac{A_t(1-\tau_t)}{\chi}\right]^{\frac{1}{\omega-1}} \tag{1.C.9}$$

$$\tau_t - \tau = \gamma_b\left(b_t^d - b\right) \tag{1.C.10}$$

$$z_t = \begin{cases} (1-\rho_z)z + \rho_z z_{t-1} + \epsilon_{z,t} & \text{for } S_{Z,t} = 1 \\ \mu z_{t-1} + \epsilon_{z,t} & \text{for } S_{Z,t} = 2 \end{cases} \tag{1.C.11}$$

$$\log\left(\frac{A_t}{A}\right) = \rho_A \log\left(\frac{A_{t-1}}{A}\right) + \epsilon_{A,t} \tag{1.C.12}$$

$$\log\left(\frac{g_t}{g}\right) = \gamma_g \log\left(\frac{A_t}{A}\right) \tag{1.C.13}$$

1.D Non-linear computational method

1. *Policy rules.* To solve the non-linear model we use the monotone map method that is described in Coleman (1991) and Davig (2004). First, we discretize the state space for each state variable, i.e. $\Psi_t = \left\{b_t^d, d_{t-1}^H, A_t, z_t, S_{Z,t}\right\}$. Second, we solve a simplified version of the model without default ($\delta = 0$) with a first-order approximation and use these policy functions to generate an initial set of decision rules denoted by $b_t^d = f_j^b(\Psi_t)$ and $d_t^H = f_j^d(\Psi_t)$. These rules are substituted into the two core equations of the model (the Euler equations (1.3.22) and (1.3.23)). Numerical integration is used to evaluate expectations about future variables. Solving this system for the state variables at each grid point yields updated values for the decision rules, i.e. $b_t^d = f_{j+1}^b(\Psi_t)$ and $d_t^H = f_{j+1}^d(\Psi_t)$ which we use as a new guess to substitute into (1.3.22) and (1.3.23). We repeatedly update the decision rules until the decision rules converge at every grid point in the state space i.e. $|f_j^b(\Psi_t) - f_{j+1}^b(\Psi_t)| < \epsilon$ and $|f_j^d(\Psi_t) - f_{j+1}^d(\Psi_t)| < \epsilon$, where $\epsilon = 10^{-6}$. We obtain a solution of the non-linear model on our grid points. Using the decision rules $f^b(\Psi_t)$ and $f^{d^H}(\Psi_t)$ of the model, we can solve for the remaining variables.

2. *Simulation results.* Given the policy rules we simulate the model economy. We initialize the simulation in the ergodic mean for all variables and then feed in various shock sequences for our exogenous processes. Given these shock sequences, we evaluate the evolution of the endogenous states using linear interpolation. In each period we randomly draw the effective fiscal limit from the state-dependent distribution of the fiscal limit. The government defaults on the fraction δ when its debt stock exceeds the effective fiscal limit.

Chapter 2

Sovereign Borrowing, Financial Assistance, and Debt Repudiation

2.1 Introduction

Does the availability of financial assistance help to avoid sovereign defaults? In the light of the European sovereign debt crisis this question has again become a pressing concern for policymakers. The overall impact of the availability of financial assistance is a priori unclear as it leads to two counteracting effects. On the one hand, financial assistance as provided e.g. by the International Monetary Fund (IMF) or the European Stability Mechanism (ESM) can counter runs by investors due to self-fulfilling default expectations and bridge deficits in times of low output and high debt levels. On the other hand, by providing insurance the availability of financial assistance lowers risk premia for troubled countries on international capital markets for a given debt level. Such a downward shift in borrowing costs might induce governments to raise debt levels and thus increase default incentives. We analyze the implications of the availability of financial assistance quantitatively within a model of sovereign default. The model features defaults due to bad fundamentals, runs by investors due to multiple equilibria, and an official lending facility that captures the main characteristics of actual international financial institutions. Runs on sovereign debt markets constitute a major threat for indebted governments as they can push countries into default that have in principle sound fundamentals and would not default otherwise. An official lending facility can help to prevent the possible coordination failure as financial assistance supplies the government with funds even when there might be a run by private investors on the market for government debt.

Our model is based on the standard sovereign default model à la Eaton and Gersovitz

(1981) and builds on Cole and Kehoe (2000) by considering multiple equilibria due to runs by investors. The government of a small open economy can borrow both from private international investors and from an official lending facility. Each period the government decides whether to repay its debt or to default on its obligations. A default entails exclusion from international financial markets and a loss in output. As reported by Roubini and Setser (2004) bailout loans are de facto senior to market debt. We include this characteristic into the model: The government can either default on its market debt only or jointly on both types of debt.[1] In addition to defaults by the government that are caused by bad fundamentals, the private debt market is prone to self-fulfilling runs, in which the investors refuse to provide new credit and the government defaults. Market debt is priced endogenously by risk neutral international investors acting on perfectly competitive markets. In contrast, bailout loans are always provided according to a fix price schedule that contains a surcharge on the risk-free interest rate. Using financial assistance is therefore unattractive for a country that can borrow at the risk-free rate from international investors. However, when default risk and risk premia are high, turning to bailout loans becomes relatively more attractive. In exchange for loans, the official lending facility demands policy adjustments ('conditionality') from the government: The government has to restrict deficits as long as it keeps making use of financial assistance.

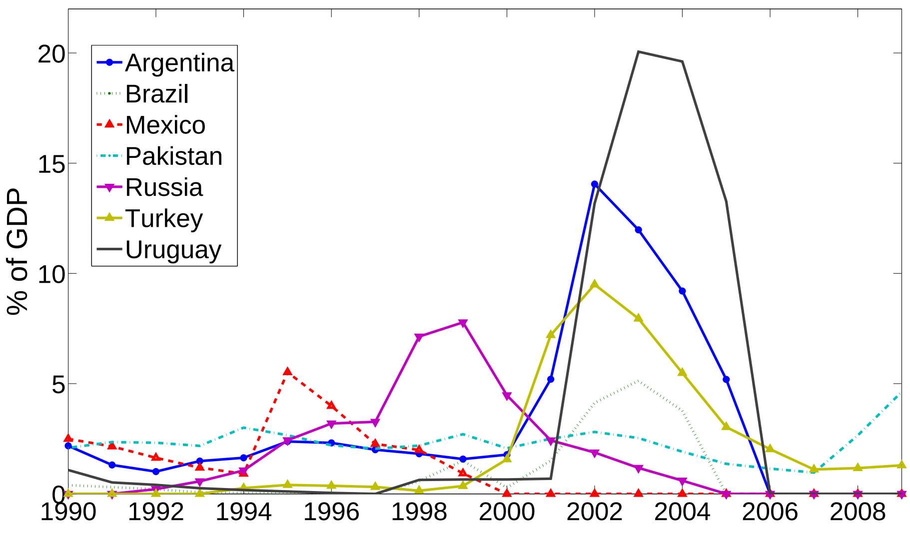
For our quantitative analysis we calibrate the model to match the data around the Argentinean default in 2001. During this crisis Argentina resorted to the IMF for financial assistance. At its peak in 2002, the use of IMF loans by Argentina reached close to 15 percent of GDP, which is at the upper end of the observed ratios for the crisis events in emerging economies between 1994 and 2002 (see Figure 2.1).[2] Our model captures key features of Argentinean business cycle statistics. To analyze the effect of the presence of the official lending facility on the default probability we compare our benchmark model and a version of the model without bailout loans. We find that the availability of financial assistance reduces the frequency of run-driven

[1] In the following the term 'market debt' denotes credit provided by private international investors on international debt markets. We use the terms 'bailout loans' or 'financial assistance' for credit provided by the official lending facility.

[2] A detailed empirical account of default events in several emerging markets economies in the 1990s and early 2000s is provided by Sturzenegger and Zettelmeyer (2006), while Roubini and Setser (2004) examine the crisis events of that time with a special focus on the implications regarding crisis resolution policies.

defaults. However, its presence leads to substantially higher debt levels and a small *overall increase* in the default probability. For a given level of market debt the presence of financial assistance reduces the probability of a default by providing credit at comparatively low interest rates when international investors charge prohibitively high interest rates. At the same time it reduces the size of the *crisis zone*. The crisis zone consists of combinations of output and debt levels for which a self-fulfilling debt run can occur due to a coordination failure among investors. The reduction of the size of the crisis zone leads to a decrease in the number of run-driven defaults. Hence, defaults on market debt become, all else equal, less likely. This insurance effect of the financial assistance reduces the interest rates charged by international investors. Lower interest rates in turn induce the country to increase its borrowing. This general equilibrium effect leads to larger average debt stocks compared to the model without financial assistance. Larger debt stocks make a government default more likely. For our benchmark calibration we find that the general equilibrium effect outweighs the insurance effect and the default probability is higher in the presence of the official lending facility.

Figure 2.1: Use of IMF credit relative to GDP of selected countries in financial crises.



Data source: Worldbank.

Our model builds on the strand of literature that analyzes the incentives of governments to default on their debt when bond contracts are unenforceable. Eaton and Gersovitz (1981) show that when default is punished, certain levels of government debt can be sustainable in equilibrium even when bond contracts are not enforceable. The government chooses not to default on its debt as long as the costs associated with a default are higher than the utility gains due to the omitted repayment. Arellano (2008) studies the quantitative implications of this model by applying it to the Argentinean default event in 2001 and shows that a calibrated version of the model is able to replicate important features of the Argentinean data. Multiple equilibria in models of sovereign default have been analyzed by Calvo (1988) and Cole and Kehoe (1996, 2000). In the Cole and Kehoe model there exists an interval of debt levels, the crisis zone, for which the government finds it optimal to default only in case it cannot issue new debt because of a run on the sovereign debt market.

This chapter is also related to recent work by Boz (2011), Fink and Scholl (2011), and Roch and Uhlig (2012) who study bailouts in a model of optimal default.[3] Boz (2011) includes bailout loans supplied by a third party (the IMF) along with market debt held by foreign private investors. She assumes that IMF credits are repaid for sure and shows that her model is able to reproduce the countercyclical use of IMF loans while market debt is used procyclically.[4] Fink and Scholl (2011) model bailout loans as a grant that is constantly available to the government and associated with a restriction on government spending. Their model is able to mimic the empirical duration and frequency of bailout programs. In contrast to our model, both papers do not consider self-fulfilling runs on side of the investors and model bailouts differently. Roch and Uhlig (2012) embed multiple equilibria into an Arellano-type model and analyze a bailout agency that possesses a sufficient amount of funds to guarantee the actuarially fair price of the sovereign debt at all times. Considering this theoretical bailout mechanism, the model illustrates the effect of a bailout agency that can distinguish between fundamental crisis and runs and eliminates self-fulfilling runs

[3] Aguiar and Gopinath (2006) briefly discuss an unconditional bailout grant in a sovereign default model with trend shocks. Benjamin and Wright (2009) analyze the impact of bailout grants in a model of debt renegotiation.

[4] Dellas and Niepelt (2011) show in a two-period model that a debt agreement with a lending partner that possesses a better enforcement technology can be beneficial both for the lending and the borrowing country, and that the bilateral loans are used more during times of crises than in times with good economic conditions and low interest rates on the private market.

completely. Similar to Roch and Uhlig (2012) we allow for runs by investors in an Arellano-type model. The focus of our model is however different as we model the official lending facility such that it captures the main characteristics of observed official lending. One of the key problems of official lenders is to identify whether the demand for bailout loans derives from a run on sovereign debt markets or from bad fundamentals. We incorporate this property into our model by the assumption that the official lending facility always provides financial assistance according to a fixed price schedule. Furthermore, we model conditionality and seniority associated with bailout loans.

Bailout loans are also considered in the literature using global games methods. Corsetti, Guimarães, and Roubini (2006) develop a three-period model to analyze bailouts and the implications of the liquidity support on moral hazard. They find that limited contingent liquidity support can help to prevent liquidity runs by raising the number of investors willing to lend to the country. Moreover, they identify circumstances in which official lending actually strengthens a government's incentive to implement desirable but costly policies. Morris and Shin (2006) find similar results.

This chapter is organized as follows: Section 2.2 decribes the benchmark model used for our analysis. Section 2.3 discusses the calibration of the model and describes the employed solution method. Section 2.4 presents the results of our quantitative analysis and Section 2.5 concludes.

2.2 Model

2.2.1 Preferences and endowments

Our analysis is set in a small open economy with an infinite time horizon. The preferences of the representative household of the small open economy are given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t u\left(c_t\right), \tag{2.2.1}$$

where c_t is consumption in period t, $\beta \in (0,1)$ is the discount factor, and E_0 is the expectation operator. The period utility function $u\left(\cdot\right)$ is strictly increasing and strictly concave and hence implies risk aversion.

The country receives a stochastic stream of endowments which follows a Markov process. In each period the benevolent government of the small open economy decides on the debt policy of the country in order to maximize the discounted sum of the household's utility by borrowing or lending on international financial markets. The government can trade bonds with international investors and has access to a limited amount of bailout loans. The bailout loans are provided by a supranational official lending facility which represents an International Financial Institution (IFI) like the IMF or bilateral agreements with other countries. All loans have a maturity of one period.[5] As long as the government repays all of its debt, the country faces the following resource constraint:

$$c = y + q^d\left(d', h', y\right) d' - d + q^h\left(h'\right) h' - h. \tag{2.2.2}$$

where y is the country's endowment income, d denotes the country's outstanding debt (i.e. positive values of d imply that the government is indebted), and q^d is the price the government receives for newly issued market bonds (next period's variables are indicated by a prime). The variable h denotes the amount of bailout loans borrowed from the official lending facility and q^h is the price of these loans.

In our model we allow for self-fulfilling crises during which a run by the investors triggers a government default. As we discuss in the next section, a sunspot shock ζ can be used to determine whether a run by the investors realizes. Similar to Cole and Kehoe (2000), the timing of actions within each period is assumed to be as follows:

1. The endowment income and the sunspot variable ζ are realized and the states are d, h, y, ζ and the credit-standing of the government.

2. The government, taking the price schedules q^d and q^h as given, chooses d' and h'.

3. The international investors, taking q^d as given, provide d'.

4. The government decides whether or not to default.

5. The government receives financial assistance h' and households consume.

[5] One period bonds are also used e.g. by Arellano (2008) and Boz (2011). Chatterjee and Eyigungor (2012) and Hatchondo and Martinez (2009) analyze long term loans with a fixed maturity while only considering one type of debt.

2.2.2 International investors

We assume that international investors are acting in perfectly competitive markets. They can borrow and lend at world financial markets at a risk-free interest rate r and are risk neutral.[6] Given that in a certain period there is no run, the international investors' profit maximization implies the following bond price equation, which ensures zero profits in expectation:

$$q^d\left(d',h',y\right) = E_{\zeta',y'|y}\left[\frac{1-\delta\left(d',h',y',\zeta'\right)}{1+r}\right]. \tag{2.2.3}$$

The investors price the bond by forming expectations over the sunspot shock ζ' and next period output y' which, along with the government debt level, influence the default decision $\delta\left(d',h',y',\zeta'\right)$. As output is assumed to follow a Markov process, expectations about next period output are formed conditional on the current output level. The indicator variable δ denotes the default decision of the government. If the government either defaults on market debt only or on both types of debt, δ takes a value of one. If there is no default and the government fulfills all its debt obligations, δ equals zero. Anticipating the government's default decision, the investors take into account the probability of a default for a given choice of d' and h' and adjust the bond price accordingly. The equilibrium interest rate on sovereign debt held by private international investors hence rises with the risk of a default as the investors demand a risk premium for compensation.

As we will explain in more detail in Section 2.2.4, there are certain combinations of the state variables d, h, and y for which self-fulfilling crises become possible. In this crisis zone there are two possible equilibria: In one equilibrium, the investors are willing to provide new lending, the government rolls over its debt, and there is no default. In the other equilibrium, the investors expect the government to default and hence do not provide new credit for a rollover of the outstanding government debt and the sovereign defaults. We use the sunspot variable ζ to determine which of these two equilibria realizes. ζ is assumed to be i.i.d. over time and takes a value of one with probability π and a value of zero with probability $(1-\pi)$. If the country is in the crisis zone, a realization of $\zeta = 1$ induces a run by the investors. The investors

[6] See Lizarazo (2013) for a model of sovereign default with risk averse lenders.

anticipate the probability of a run-driven default by the government in the next period which depends on the realization of ζ'. If there is a run already in the *current* period (induced by $\zeta = 1$), the investors are not willing to provide any lending to the government at a positive bond price. Thus the bond price in the current period is equal to zero and no longer given by equation (2.2.3).

2.2.3 Official lending facility

As long as the country is in good credit standing, it can make use of financial assistance from an official lending facility. We assume that the lending facility always provides financial assistance, independent of whether the country's demand for bailout loans derives from a run or high interest rates that are driven by bad fundamentals. Following Boz (2011), the price of bailout loans q^h is not determined by a market mechanism, but set by the official lending facility according to an exogenously fixed schedule. Hereby we capture the fact that the lending conditions of the official lending facility are rather guided by political decisions (which we do not model) than by pure profit considerations. Consistent with the actual price schedule of IMF loans, we assume that the price depends on the amount of bailout loans demanded.[7] The exogeneity of the bond price for bailout loans makes it necessary to impose a maximum h_{max} on the amount of bailout loans. Otherwise a country in good credit standing could always borrow arbitrarily large amounts before declaring default in the next period.[8] To capture important characteristics of actual official lending we model bailout loans to be senior to market debt (see Section 2.2.4). Furthermore, we assume that the official lending facility possesses a better punishment technology than the private international investors, i.e. the punishment after a default on bailout loans is stronger than the punishment after a default on market debt only. This seems plausible as a default on bailout loans might lead to an even stronger loss of

[7] According to the IMF's lending policies for the so called 'stand-by arrangements', the effective total interest rate demanded from borrowers consists of a number of different fees and charges that are added to the riskless interest rate (International Monetary Fund, 2012). Some of the additional charges are independent of the size of the loans (e.g. there is a 50 basis points service charge). Other surcharges on the interest rate are increasing with the size of the demanded IMF loans, as e.g. the 'surcharge for large loans' of 200 basis points for loans sizes above 300 percent of the country's quota.

[8] This problem does not exist when the bond price is determined on the private debt market. In this case, international investors assess the default probability and the bond price falls to zero when the default probability approaches one.

reputation. Moreover, the official lenders might use political measures like sanctions, which are not available to international investors, to punish the defaulting country.

The government can only borrow from the official lending facility if it complies with conditionality obligations set by the facility. The IMF provides loans to troubled countries conditional on certain policy adjustments. The requirements of this conditionality are aimed at resolving the balance of payment and government debt problems of the borrower. They include macroeconomic and structural measures (Bird, 2007). An additional rationale for imposing conditionality is to alleviate debtor moral hazard problems (Guitián, 1995). A large part of these measures is related to fiscal policy and may include amongst others limits on the budget deficits and on the level of external debt (International Monetary Fund, 2002). We capture important program features by assuming that a government that is borrowing from the official lending facility has to follow a debt adjustment program. As long as the government holds positive amounts of bailout loans, its decision on new debt is bounded by the following constraint on total new borrowing:

$$d' + h' \leq \lambda \left(d + h\right). \tag{2.2.4}$$

The parameter λ determines the strictness of the conditionality: For λ above one, the total debt of the country is still allowed to increase, but at most by $(\lambda - 1) \times 100$ percent per period. For a λ below one, total debt has to decrease by $(1 - \lambda) \times 100$ percent per period. For the case of a default on market debt we assume $\lambda = 1$ which implies that the country may not increase its amount of bailout loans.

2.2.4 Decision problem of the government

In each period the government decides on its debt policy. The government has to decide whether to default or not and, in case it does not default on its old debt, the government has to choose the amount of new debt (market debt and bailout loans). We assume that the country can either default on market debt only or on both market debt and bailout loans at the same time. We allow for the former option because historical evidence shows that countries defaulted on their debt obligations to private international investors while receiving IMF support (see e.g. Sturzenegger and Zettelmeyer, 2006). However, a default on bailout loans without simultaneous default on market debt is not allowed as loans from the IMF are de facto senior to market debt (see Roubini and Setser, 2004).

The government's choice between the different options depends on the specification of the respective consequences. As commonly assumed in the literature, default always occurs on the full amount of outstanding debt.[9] After a default, the country is excluded from financial markets for a limited time and incurs an output cost $l(y) \geq 0$.[10] During the exclusion period the country can thus only consume its endowment net of the output cost: $y_t^{def} = y_t - l(y_t)$. A country that has defaulted on its debt only regains access to financial markets with a certain probability. While we assume the output cost to be the same for both types of default, the average exclusion length depends on the type of default. A country that defaults on market debt only is modeled to have a shorter average exclusion length than a country that defaults on both market debt and bailout loans simultaneously. We therefore distinguish between the probability to return to financial markets after a default on market debt only, θ, and the probability to return to financial markets after a default on both types of debt, θ_H, with $\theta \geq \theta_H$. Both probabilities are assumed to be constant over time. The difference in average exclusion length reflects that the official lending facility has a stronger commitment to punish a defaulting sovereign than a private creditor.

The value function of being in good credit-standing $V^o(d, h, y, \zeta)$ depends on the amount of outstanding debt (market debt and bailout loans), the income state, and the sunspot variable ζ. It is given by the maximum of the three possible options of repayment or default:

$$V^o(d, h, y, \zeta) = \max\left\{V^c(d, h, y, \zeta), V^{defD}(h, y), V^{defDH}(y)\right\}. \tag{2.2.5}$$

V^c is the value function of repayment of both types of debt. In this case the country fulfills its contractual obligations, i.e. it pays back its outstanding debt (market debt and bailout loans), and chooses the optimal level of new market debt and bailout loans. V^{defD} is the value function of defaulting on market debt only and consequently continuing without access to private credit markets. V^{defDH} is the value function of

[9] An exception is Yue (2010), who considers a model of debt renegotiation where the haircut is determined in a Nash bargaining between debtor and creditor. Other exeptions include Benjamin and Wright (2009), Bi (2008) and D'Erasmo (2011).

[10] For a discussion of the empirical evidence see Panizza, Sturzenegger, and Zettelmeyer (2009).

defaulting on both market debt and bailout loans and losing access to both types of borrowing.

For the implementation of self-fulfilling default crises we follow Chatterjee and Eyigungor (2012) by assuming that in case of a default in the current period the government has to return new loans d' without any interest payments to the international investors. The value function V^{defD} is therefore independent of the amount of new loans d'. Nevertheless, runs by the international investors as in Cole and Kehoe (2000) are possible as any international investor would loose interest earnings in case she provides new loans and the government defaults in the same period.[11]

The value function associated with a default on market debt only, V^{defD}, is given by:

$$
\begin{aligned}
V^{defD}(h,y) = \max_{\{h'\}} \Bigg\{ & u\left(y^{def} + q^{h}(h')\,h' - h\right) \\
& + \beta \int_{y'} \Big[\theta\Big[(1-\pi)\,V^{o}(0,h',y',0) + \pi V^{o}(0,h',y',1)\Big] \\
& \qquad + (1-\theta)\,V^{defD}(h',y')\Big] f(y',y)\,dy' \Bigg\}
\end{aligned}
\tag{2.2.6}
$$

subject to

$$
\begin{aligned}
& h' \le h \qquad \text{if} \quad h > 0 \\
& 0 \le h \le h_{max}.
\end{aligned}
$$

In this case, the country still fulfills its contractual obligations with the official lending facility, but has zero market debt as it just defaulted. The value function V^{defD} is therefore independent of d and the sunspot shock ζ. With probability θ the country can return to international financial markets in the next period. π is the probability that the sunspot variable takes a value of one. $f(y',y)$ denotes the transition probability to income state y' in the next period given income state y in the current period.

After a default on both types of debt the country has no access to further borrowing and the households can only consume the endowment. The value function for a

[11] The detailed within-period timing of actions that leads to the potential emergence of self-fulfilling crisis is outlined in Section 2.2.1.

default on both types of debt, V^{defDH}, is given by:

$$V^{defDH}(y) = u\left(y^{def}\right) + \beta \int_{y'} \Big[\theta_H \big[(1-\pi) V^o(0,0,y',0) + \pi V^o(0,0,y',1)\big] + (1-\theta_H) V^{defDH}(y')\Big] f(y',y)\, dy'. \tag{2.2.7}$$

The value function of debt repayment, V^c, is given by:

$$V^c(d,h,y,\zeta) = \max_{\{d',h'\}} \Big\{ u\Big(y + q^d(d',h',y)\, d' - d + q^h\left(h'\right) h' - h\Big) + \beta \int_{y'} \Big[(1-\pi) V^o(d',h',y',0) + \pi V^o(d',h',y',1)\Big] f(y',y)\, dy' \Big\} \tag{2.2.8}$$

subject to

$$(d'+h') \leq \lambda(d+h) \qquad \text{if} \quad h > 0$$
$$0 \leq h \leq h_{max}.$$

For certain combinations of the state variables the government prefers to repay its debt only if it has access to new borrowing but it defaults if it cannot roll over its maturing debt. In this case self-fulfilling debt runs can emerge due to a coordination failure among international investors. Given that there is a run by the investors, the country has no access to new market debt ($d' = 0$). To facilitate the following exposition, we introduce V^c_{run} to denote the value function of repayment *in case of a run*, i.e. V^c_{run} is V^c for combinations of the state variables that imply a run. V^c_{run} is given by:

$$V^c_{run}\left(d,h,y,1\right) = \max_{\{h'\}} \Bigg\{ u\Big(y - d + q^h\left(h'\right)h' - h\Big) \tag{2.2.9}$$
$$+ \beta \int_{y'} \Big[\left(1-\pi\right) V^o\left(0,h',y',0\right) + \pi V^o\left(0,h',y',1\right) \Big] f\left(y',y\right) dy' \Bigg\}$$

subject to

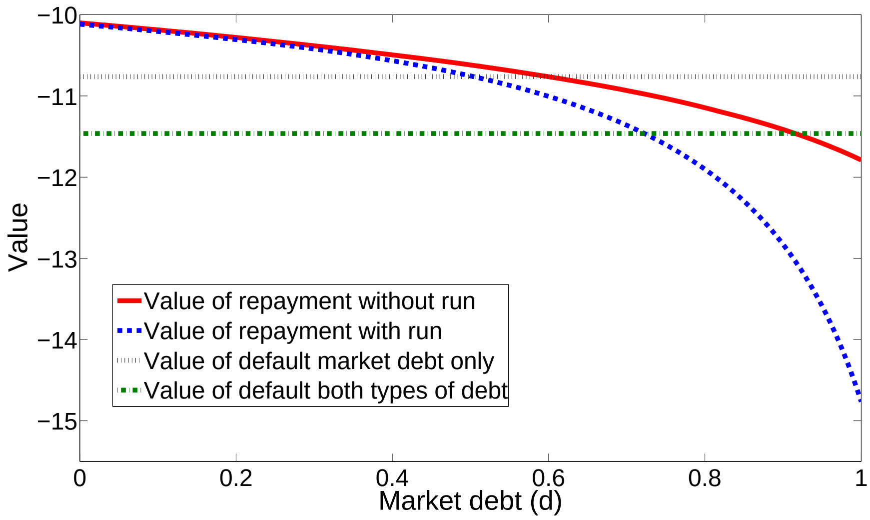
$$\left(d'+h'\right) \leq \lambda\left(d+h\right) \qquad \text{if} \quad h > 0$$
$$0 \leq h \leq h_{max}.$$

Figure 2.2 illustrates the decision problem of the government. It shows the four different value functions for an intermediate output level in a situation where the government has no outstanding bailout loans. The two value functions of repayment decrease in the level of outstanding debt as the funds repaid to the investors cannot be consumed by the households.[12] For low levels of market debt, both the value of repayment without a run, $V^c\left(d,h,y,0\right)$, and the value of repayment with a run, $V^c_{run}\left(d,h,y,1\right)$, lie above the value of default, which does not depend on the level of outstanding debt. In this region the government would not default even if there was a run by the investors. Anticipating this, the investors would not run in the first place and no self-fulfilling crisis is possible for the given state combination. However, with increasing levels of outstanding debt the distance between $V^c\left(d,h,y,0\right)$ and $V^c_{run}\left(d,h,y,1\right)$ increases and for an interval of intermediate amounts of outstanding debt $V^c\left(d,h,y,0\right)$ lies above $V^{defD}\left(h,y\right)$, while $V^c_{run}\left(d,h,y,1\right)$ lies below $V^{defD}\left(h,y\right)$. This is the crisis zone where self-fulfilling crises become possible as the government only prefers to default in case of a run. Rational investors anticipate the behavior of the government. Consequently, if an individual investor expects the other investors *not* to roll over the debt, she will anticipate a government default and will not be willing to lend to the government either as this would lead to the loss of interest earnings. Given that the investors are not willing to roll over the debt, the government

[12] For this illustration, we compute $V^c_{run}\left(d,h,y,1\right)$ also for levels of outstanding market debt for which in equilibrium no run occurs. $V^c\left(d,h,y,0\right)$ is always larger or equal to $V^c_{run}\left(d,h,y,1\right)$, as a run restricts the options of the government. Without a run the government could always choose $d'=0$ and be at least as well off as in the case of a run.

defaults. However, in case an individual investor expects all other investors to roll over the debt, she knows that the government will not default and she is also willing to buy new bonds. Given that the government can roll over its debt, it does not default in equilibrium. Therefore, there exist combinations of the state variables for which there are two possible equilibria, one with rollover and no default and one without rollover and a default by the government. Which of these equilibria is actually realized is determined by the realization of the sunspot variable ζ. For high levels of debt not only $V^c_{run}(d,h,y,1)$ but also $V^c(d,h,y,0)$ is lower than the value of default $V^{defD}(h,y)$. In this case the government defaults for sure, independent of the rollover decision of the investors.[13]

Figure 2.2: Values of possible government choices for given levels of market debt



Notes: Values are calculated for a government without outstanding bailout loans and an intermediate output level. Computations are based on the benchmark calibration outlined in Section 2.3.

Definition: Given the parameters, the output process, and the price schedule for bailout loans, the recursive equilibrium for this economy is defined by the set of policy

[13]The position of $V^{defDH}(y)$ relative to $V^{defD}(h,y)$ depends on the level of outstanding bailout loans. The government chooses the default option that yields the higher value. The emergence of the three regions holds independent of which of the two values of default is the higher one.

functions c, d', h', the default decision function of the government, and the bond price function $q^d(d', h', y)$ such that:

1. Given the government's policies, the country's resource constraint is satisfied.
2. Taking as given the bond price schedule $q^d(d', h', y)$ and possible runs by the investors, the government's policies d', h', and its default decision solve the government's optimization problem.
3. The bond price $q^d(d', h', y)$ reflects the default probabilities and ensures zero profits in expectation for the investors. When there is a self-fulfilling run, the bond price $q^d(d', h', y)$ is equal to zero.

2.3 Calibration

We solve the model numerically. Therefore, we need to assume specific functional forms and assign parameter values. The utility function of the representative household is a constant relative risk aversion utility function given by:

$$u(c) = \frac{c^{1-\sigma}}{1-\sigma}. \tag{2.3.1}$$

The income process is given by an AR(1) process for $\log(y)$:

$$\log(y_t) = \rho \log(y_{t-1}) + \eta_t \tag{2.3.2}$$

where $\eta_t \sim N\left(0, \sigma_\eta^2\right)$. The output costs are modeled as in Chatterjee and Eyigungor (2012) by a non-linear function:

$$l(y) = \max\left\{0, l_0 y + l_1 y^2\right\}. \tag{2.3.3}$$

where $l_1 \geq 0$. This convex cost function implies that a default is more costly in the case of a high output realization than in a period with low output.[14] The state-dependence of the output cost function is necessary to generate a sufficient number of defaults in equilibrium by inducing a strong relation between the default decision

[14]The convexity of the cost function can also be generated endogenously in a production economy with working capital loans for foreign intermediate inputs (see Mendoza and Yue, 2012).

and the output level.[15] If a good income state is likely for the next period, bond prices are high and the country can accumulate high debt stocks on which it defaults when the output level is low.

In line with the interest rate schedule of the IMF, the price for the bailout loans is assumed to depend on the borrowed amount. As in Boz (2011) the official lending facility demands a linearly increasing surcharge $\psi\left(h'\right)$ on the risk-free interest rate:

$$q^h(h') = \frac{1}{1 + r + \psi\left(h'\right)}, \tag{2.3.4}$$

where

$$\psi\left(h'\right) = \psi_{min} + \frac{\psi_{max} - \psi_{min}}{h_{max}}\, h'. \tag{2.3.5}$$

We calibrate the model at quarterly frequency using data for the Argentinean economy before its sovereign default in 2001. As Chatterjee and Eyigungor (2012) point out, from 1993 to 2001 Argentina was at the same time in a currency board regime pegging the Argentinean Peso to the US Dollar and borrowing via marketable bonds on international credit markets. This makes this time period especially suitable for the analysis of the model. The parameter values of our benchmark calibration are stated in Table 2.1.

The relatively low discount factor β can be interpreted as indicating the strong impatience of the government of the economy which is mainly concerned about the short-run. β is set to match the average ratio of market debt to quarterly GDP and lies in the range of values considered in the literature. To compute Argentinean debt levels, we use data on external public debt provided in the World Bank's Global Development Finance Database. As the series is annual and our model is quarterly we have to transform the data. At yearly frequency, the average ratio of debt held by private international investors to GDP in the years from 1993 to 2000 is 16.3 percent which implies a quarterly value of approximatively 65.2 percent. Following Chatterjee and Eyigungor (2012) we target only 70 percent of this debt-to-GDP ratio as this was roughly the size of the haircut after the Argentinean default.[16] Consequently, only

[15] Arellano (2008) shows that even without (state-dependent) output costs as in equation (2.3.3) default incentives are decreasing in the endowment.

[16] See Sturzenegger and Zettelmeyer (2008) for an estimate of the size of the haircuts in several default events.

Table 2.1: Calibration to Argentinean data

Parameter		Value	Target/Source	Value
Discount factor	β	0.9005	Debt-to-GDP-ratio	0.456
Risk aversion	σ	2	Literature	
Autocorrelation $\log(y_t)$	ρ	0.945	Argentinean data	
Std. dev. output shock	σ_η	0.025	Argentinean data	
Risk-free rate	r	0.01	Literature	
Reentry prob. - defD	θ	0.125	Avg. exclusion length	2 years
Reentry prob. - defDH	θ_H	0.025	Estimate	
Output costs	l_0	-2.34	Default probability	3.1%
Output costs	l_1	2.508	Std. dev. interest spread	4.58
Max. of bailout loans	h_{max}	0.25	Observed max. in data	0.2
Debt adjustment	λ	1.01	Max. deficit (% of GDP)	1.85
Interest surcharge	ψ_{min}	0.00125	IMF service charge	0.5% p.a.
Interest surcharge	ψ_{max}	0.113	Mean h/y	0.053
Run prob. in crisis zone	π	0.16	Corr(y, $\Delta d/y$)	0.141

this share of the debt (45.6 percent of quarterly GDP) is considered as the unsecured and hence defaultable debt stock. The parameter of risk aversion σ is set to 2, which is a standard value in the literature. The output process is estimated using Argentinean data from the 20 years before the default event, taken from the dataset by Neumeyer and Perri (2005). We take the logarithm of deseasonalized quarterly real GDP data and detrend the series with a linear trend. The risk-free rate is equal to one percent per quarter, which implies an annual real rate of roughly four percent, a standard value in the real business cycle literature. The value of the reentry probability after a default on market debt only, θ, lies in the range of values used in the literature and is consistent with the estimates of Gelos, Sahay, and Sandleris (2011), who report only short periods of exclusion from international financial markets. Specifically, the median duration of exclusion after a sovereign default in the 1990s was two years. There is no empirical counterpart for θ_H as until now there has been no outright default on IMF credits of an emerging market economy. The value of θ_H employed in our calibration implies on average 10 years of exclusion and is an estimate based on the fact that Argentina still has not fully returned to international financial markets since its default in 2001, which involved major disagreements between the Argentinean government and the IMF. In Section 2.4.5 we show that our results are robust against considering a higher value of θ_H, i.e. a shorter average exclusion after a default on both types of debt. The first parameter of the output cost function, l_0, is set to match the default frequency of 3.1 percent (in annual terms) observed in Argentina.[17] The second parameter, l_1, is set to match the standard deviation of the interest rate spread which is 4.58 in the data.[18] The values of h_{max} and λ are consistent with past IMF programs. We choose a h_{max} of 25 percent of average output, which is slightly higher than the largest amount of IMF loans used by Argentina, which was around 20 percent of pre-crisis output (see Roubini and Setser, 2004). The debt adjustment of $\lambda = 1.01$ is equivalent to a maximum debt increase of 3.9 percent per year which is approximately equal to an allowed deficit of 1.85 percent of GDP per year.[19] The minimum surcharge, ψ_{min}, is set to 0.00125, which equals a 50 basis points service charge (annually) demanded by the IMF. The maximum value of the linearly increasing interest rate surcharge, ψ_{max}, is set to match the mean ratio of bailout loans to quarterly GDP which is 0.053 for the period from 1970 to 2000.[20]

The probability of a run in the crisis zone, π, cannot be observed in the data. We set the parameter to match the correlation of output with the change in market debt relative to output, corr(y, $\Delta d/y$). This correlation has a value of 0.141 and is calculated for the time period 1993-2000, which is not affected by debt restructuring or default. Defaults that are caused by runs occur both at relatively high and at low output levels. Increasing π leads to a rise in the number of run-driven defaults and thereby decouples the risk of a default and consequently the bond price from the output level. This yields a decrease in the correlation. In our benchmark calibration π is set equal to 0.16.

We solve the model by value function iteration. Starting with a guess for the bond

[17] To obtain this estimate, we use the default and rescheduling events documented by Reinhart and Rogoff (2009), which can be clustered to six default episodes from Argentinean independence in 1816 until 2011.

[18] The spread is calculated as the difference between the Argentinean interest rates reported by Neumeyer and Perri (2005) and the rate of a 3-month U.S. Treasury bill in the period from 1993Q1-2001Q4.

[19] See International Monetary Fund (2003) for actual targets of the Argentinean program. Specifically, allowed deficits for the first two years of the program were 2.3 percent and 1.4 percent of GDP. One can transform the deficit targets (measured in percent of GDP) into maximum debt increases by dividing them by the debt-to-GDP level targets for the respective year (which have been 0.477 and 0.473 in 2000 and 2001).

[20] The mean ratio of IMF loans to GDP in annual data is 0.0132, which implies a quarterly value of approximatively 0.053.

price schedule we compute the optimal policies of the government. Given these policies we compute the probabilities of a default in the next period depending on the choices of new loans (market debt and bailout loans) and the given output realization. These probabilities then enter into an update of the bond price function. This procedure is repeated until convergence. We discretize the state space by approximating the log output process with the Tauchen algorithm using 31 grid points. The mean of the log output process is set to zero. For the dimension of market debt we use a grid of 300 points within the interval [-0.1; 1.0] that spans the asset space from ten percent assets to hundred percent debt relative to a quarterly output of unity. For the dimension of bailout loans the grid consists of 40 points within the interval [0; 0.25].

2.4 Results

2.4.1 Business cycle statistics

To assess the performance of the model, we simulate the model and compare the resulting business cycle statistics with the corresponding statistics from Argentinean data.[21] Table 2.2 shows that the results for the benchmark calibration are in line with the data. Consumption is more volatile than output. All of the correlations have the correct signs: Consumption and output show a strong co-movement, while the interest rate spread (on market debt) and the trade balance are both countercyclical. We target an overall default probability of 3.1 percent. The resulting probability of a run-driven default is 0.9 percent, which means that more than a quarter of the defaults is caused by runs. For the benchmark calibration there are no joint defaults on both market debt and bailout loans. The model nearly matches the number of periods that the country uses bailout loans. We calibrate our model to match the average debt stock of Argentina. In accordance with the data, the model implies that market debt is used procyclically, while the use of bailout loans is countercyclical.

[21] We simulate the model for one million quarters and exclude default and exclusion periods. Additionally, similar to Chatterjee and Eyigungor (2012), we exclude two years after redemption as the country counterfactually returns to financial markets with zero debt. We calculate the business cycle statistics over the more than 870,000 remaining episodes.

Table 2.2: Business cycle statistics

Variable	Benchmark model	Data
Std. dev. output	6.82	7.68 *
Std. dev. consumption	9.27	8.38 *
Std. dev. interest rate spread	4.56	4.58 **
Std. dev. trade balance	4.47	1.50 **
Corr(output, interest rate spread)	-0.41	-0.79 **
Corr(output, trade balance)	-0.31	-0.81 **
Corr(output, consumption)	0.88	0.98 *
Corr(interest rate spread, trade balance)	0.61	0.82 **
Default prob. market debt	3.1%	3.1%
→ of which due to runs	0.9%	-
Default prob. market debt and fin. assist.	0.0	0.0
Prob(h>0)	0.55	0.60
Average market debt (% of GDP)	45.6	45.6
Average financial assistance (% of GDP)	5.3	5.3
Average spread market debt	3.9	8.15
Corr(y, $\Delta d/y$)	0.141	0.141
Corr(y, $\Delta h/y$)	-0.06	-0.15

Notes: Data on output, consumption, interest rates, and trade balance from Neumeyer and Perri (2005). Spreads are calculated based on the rate of 3-month U.S. Treasury bills (data from FRED). Data on bailout loans from World Bank and International Financial Statistics (IFS), market debt from World Bank. Calculations are for 1980Q1-2001Q4 (*) and 1993Q1-2001Q4 (**). Prob(h>0) is calculated for 1946Q1-2011Q4. Debt levels are at quarterly frequency. For calculation of default probability, debt levels, and spread see Section 2.3. Due to limited data availability corr(y, $\Delta d/y$) is reported for annual data. corr(y, $\Delta h/y$) and the other correlations and std. dev. are reported for quarterly data. The average spread on market debt is reported in annualized terms.

2.4.2 Effects of financial assistance

Given that the model successfully matches the data, we turn to answering our initial question of how the presence of financial assistance affects the probability of a government default. We compare the outcome of our benchmark model with the results obtained by simulating a version of our model that does not feature the official lending facility. For this comparison we apply the parameter values of the benchmark calibration in both models. The results summarized in Table 2.3 show that without the availability of bailout loans the overall default probability is slightly lower than in the benchmark model (3.0 vs. 3.1 percent). This overall default probability is partly caused by run-driven defaults. Without the lending facility there are substantially more run-driven defaults (1.4 vs. 0.9 percent). We find that the model without the lending facility exhibits on average a lower total debt level than the benchmark model (35 vs. 51 percent of quarterly GDP). While, by definition, there are no bailout loans in the model without the lending facility also the average level of debt borrowed from private international investors is lower than in the benchmark model. Our results imply that an official lending facility can in fact help to reduce the probability of runs by the investors. However, it also substantially decreases the incentive for countries to limit their debt levels. In total, the probability of default is higher when financial assistance is available. This results from the fact that the increase in the default incentives due to higher debt levels outweighs the lower probability of run-driven defaults.

Table 2.3: Effect of financial assistance on default probability and debt levels

Variable	benchmark model	model w/o fin. assistance
Default probability market debt	3.13%	2.98%
$\rightarrow$ of which due to runs	0.90%	1.41%
Avg. market debt (% of GDP)	45.6	34.9
Avg. fin. assist. (% of GDP)	5.3	-

2.4.3 Model dynamics

Turning to the underlying economic mechanisms of the model, we find that it preserves several important features of standard sovereign default models. First, the incentive to default is growing with the amount of debt as higher debt levels increase the possible gain of not repaying. Second, given a low realization of output repaying a certain amount of debt leads to lower consumption than repaying the same amount given a high realization of output. Therefore, default incentives are stronger for low output states than for high output states. Figure 2.3 depicts the default decision of a government that has no outstanding financial assistance (left panel) and of a government that already uses the maximum amount of available financial assistance (right panel). The black areas indicate combinations of output realizations and market debt holdings for which the government decides to default on its market debt. The government refrains from a default when output is high and debt is low (white area). The crisis zone (grey area) is located between the two areas in which the government always or never defaults. Self-fulfilling runs by the investors can only materialize when the default decision of the government depends on the decision of the investors to run. For high market debt and low output the government always prefers to default, independent of a possible run by the investors. Likewise, the government would always prefer to repay its debt in low debt and high output combinations, even if there was a run by the investors (which would have the consequence that the government could not roll over its debt). With rising debt levels and decreasing output a default becomes more and more attractive for the government. A run by the investors can then become decisive for whether or not the government defaults. This leads to the emergence of self-fulfilling expectations by the investors. A comparison of the left and the right panel of Figure 2.3 illustrates that the crisis and default zones are larger when the country already uses the maximum amount of financial assistance. This reflects the fact that the insurance effect of financial assistance is stronger the more of financial assistance is still available. Moreover, default incentives are stronger when the country borrows from the official lending facility in addition to its market debt as it has to pay back a larger total amount of debt.

Figure 2.3: Default decision of the government

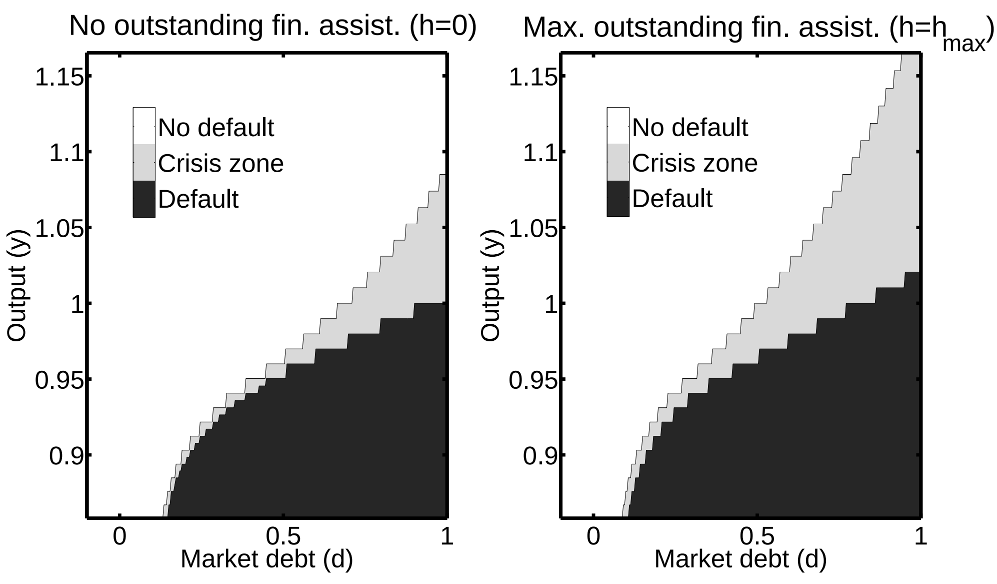
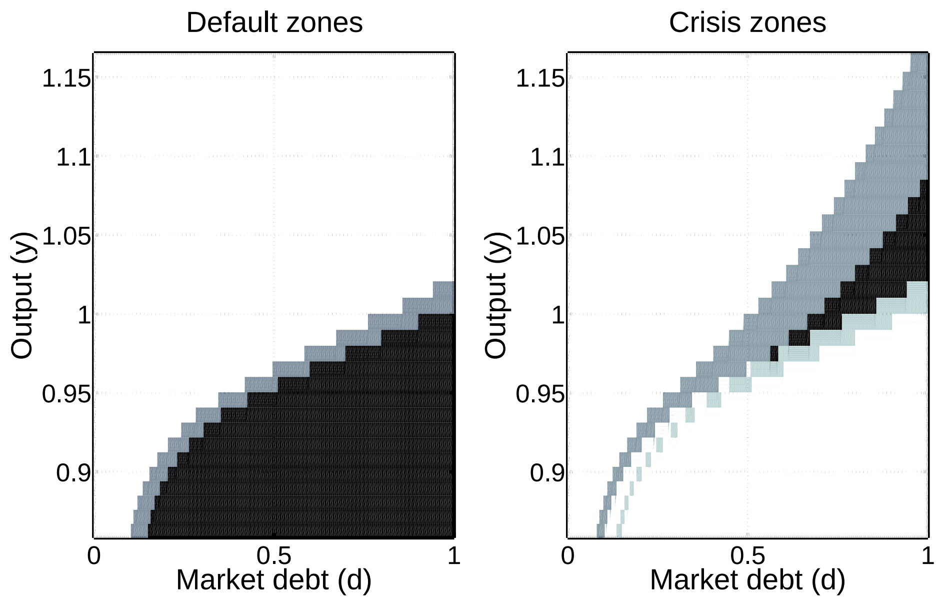


Figure 2.4 compares the default decision of the government in our benchmark model with the default decision of the government in the model in which no bailout loans are available. The left panel of Figure 2.4 shows that the default region is larger in the model without bailout loans. While the black area in the left panel of Figure 2.4 indicates where the default zones of the two models overlap, the grey area denotes combinations of output and debt for which the government defaults only in the model without the official lending facility. The availability of bailout loans also reduces the size of the crisis zone as illustrated in the right panel of Figure 2.4. The figure shows the crisis zone in the benchmark model for a government that has no outstanding bailout loans and compares it to the crisis zone in the model without bailout loans. While for certain state combinations the crisis zone prevails in both models (black area), the dark grey area to the left of the black area indicates those state combinations for which self-fulfilling crises occur only in the model without the official lending facility. For a few state combinations there exists a crisis zone only in the model with bailout loans (light grey area to the right of the black area). However, in the model without the official lending facility the government defaults in this area for sure. The overall reduction in the size of the crisis zone is substantial. Once the country uses all of the available bailout loans this effect vanishes and the crisis zones are almost identical in the two model versions (right panel of Figure 2.8 in Appendix 2.A). Both the reduction in the size of the default region and the crisis region make a default of the government for a given debt level less likely due to the insurance effect of financial assistance.

As defaults are less likely (for a given debt level) when the official lending facility is present, the international investors charge lower interest rates than when no financial assistance is available. Figure 2.5 illustrates the resulting shift in the bond price schedule. The bond price drops as debt levels increase. The continuous (black) lines denote the bond price schedule in the benchmark model for a government that has no outstanding bailout loans, but has them at its disposal. The dashed (blue) lines denote the schedule for a government in the model without the official lending facility. The availability of financial assistance shifts the bond price schedule to the right, resulting in lower interest rates for the government. The effect is present both at low output levels (left panel) and at high output levels (right panel). Facing a more favorable interest rate schedule, the government on average borrows a larger amount

Figure 2.4: Comparison of default zones (left panel) and crisis zones (right panel)

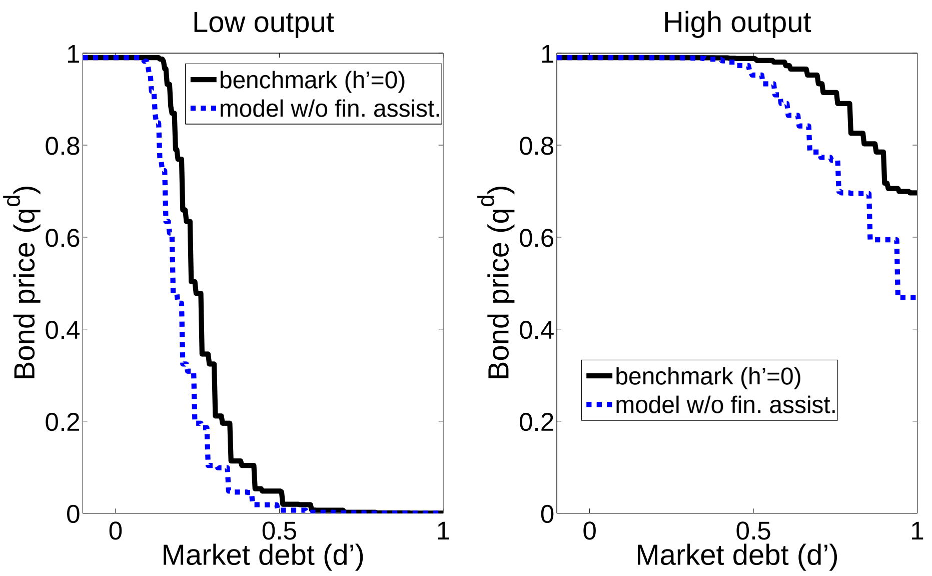


Notes: black areas: zones overlap, grey areas: default/crisis only when no financial assistance is available, bright grey area: crisis zone only in the model with financial assistance.

of debt when the official lending facility is present. Figure 2.5 also shows that the fall of the bond price occurs at lower debt levels when the output realization is low (left panel in comparison to right panel). Taking into account that default incentives increase for bad output realizations, investors charge higher interest rates for any amount of market debt demanded. The interest rate of market debt therefore follows a countercyclical pattern. The government reacts by demanding less market debt when output is low and by demanding more market debt when output is high. Hence, the government borrows procyclically on private bond markets (see also Table 2.2).

The smaller size of the default and crisis zone in the benchmark model stems from the fact that the government turns to official lending instead of choosing an outright default. Figure 2.6 shows the demand for financial assistance of a government that has no outstanding bailout loans. The chosen volume of bailout loans increases for lower output realizations and for higher levels of outstanding market debt. For very low output and high market debt the demand for bailout loans is again zero as in this case

Figure 2.5: Comparison of equilibrium bond price schedules for market debt

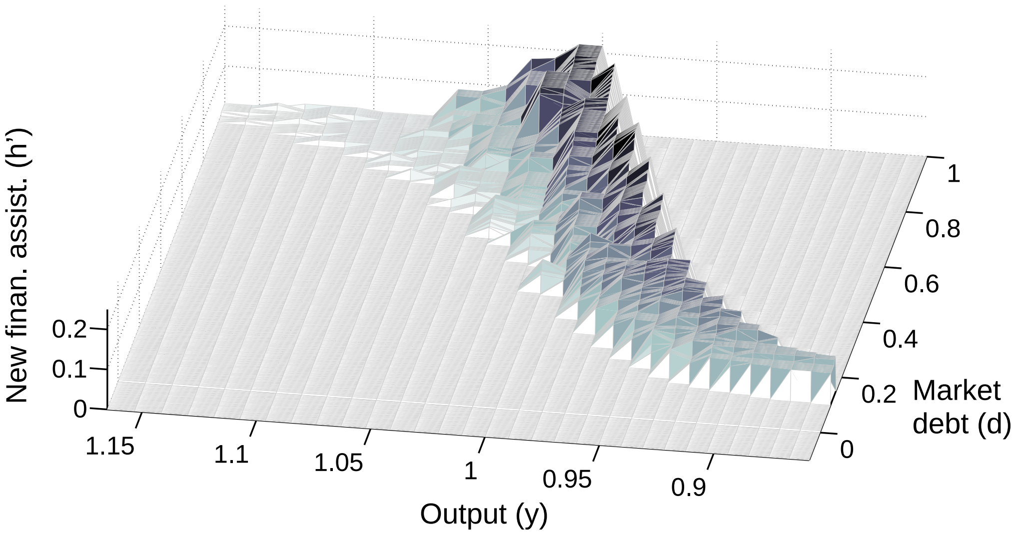


the government prefers to default on market debt without using bailout loans. The region in which the demand for bailout loans spikes corresponds to the reduction of the crisis zone in the right panel of Figure 2.4. While the bond price for market debt falls rapidly when output levels are low (see Figure 2.5), the interest rate schedule of bailout loans is fixed independent of output levels. The government therefore substitutes market debt by bailout loans when output realizations are relatively low. However, due to the additional charges and fees of bailout loans, in good output states market debt is cheaper and the government demands no bailout loans. As a consequence the resulting demand for bailout loans is countercyclical.

2.4.4 Welfare

Despite the fact that the presence of the official lending facility is associated with a higher default probability, the welfare implications of bailout loans are a priori unclear. Having an additional borrowing opportunity can potentially improve the country's welfare. Also, there is a possible welfare gain as the official lending facility helps to (partly) resolve the inefficiency generated by the coordination failure of private international investors. The limited commitment of the sovereign and the presence of incomplete markets might, however, lead to a situation in which the

Figure 2.6: Choice of financial assistance (for $h = 0$)



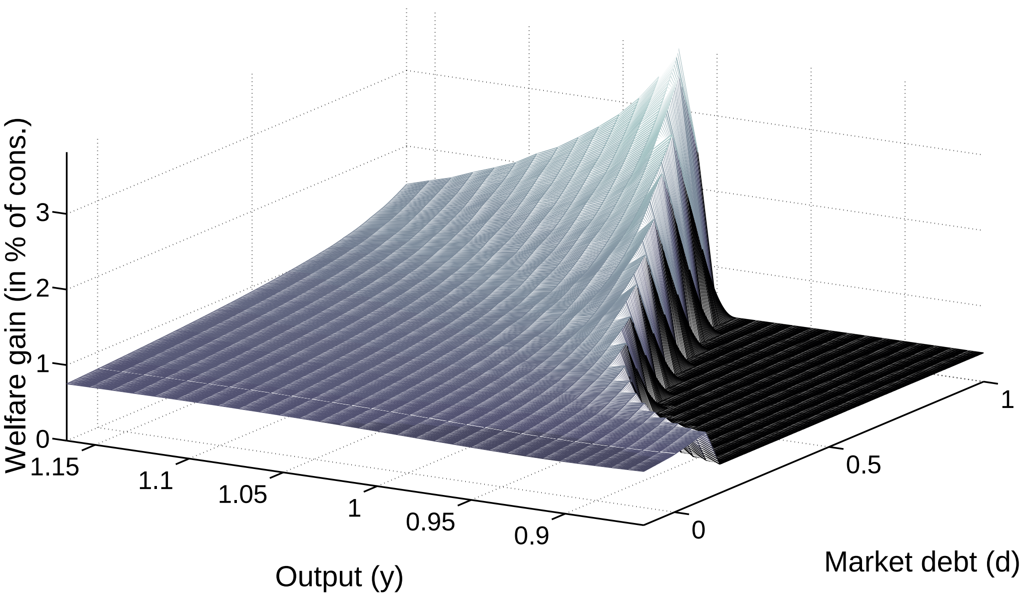
country is worse off if financial assistance is available. Without the official lending facility the government has only one defaultable (i.e. state-contingent) bond at its disposal. Having an additional borrowing opportunity, however, changes the default incentives and hence influences the endogenous price schedule. The shift of the price schedule changes the constraints of the optimization problem of the government and it chooses much higher equilibrium debt levels which are also associated with higher interest rate payments. To assess the welfare implications numerically, we compare the certainty equivalent consumption in the benchmark model and in the model without financial assistance. More precisely, we compute the amount of additional consumption that is necessary to make households indifferent between living in the model with financial assistance and without financial assistance.[22]

As a first step, we conduct a state by state comparison. This comparison is similar to establishing a new official lending facility in a world without financial assistance. Figure 2.7 displays the resulting welfare gain (in percent of certainty equivalent consumption) due to the availability of financial assistance. The country benefits from the additional borrowing opportunity in case it has no outstanding bailout loans.

[22]For the welfare comparison we solve for g in the equation $g^{1-\sigma}V^{FA}(d,h,y,\zeta) = V^{no\ FA}(d,y,\zeta)$, where V^{FA} is the country's value function of being in the benchmark model with financial assistance and $V^{no\ FA}$ the value function of being in the model without financial assistance.

Outstanding bailout loans automatically imply higher total repayment obligations and therefore have an impact on utility levels. Consequently, the state by state comparison is only meaningful for a government that currently does not have outstanding bailout loans. The state-dependent welfare gain depicted in Figure 2.7 ranges from 0.3 percent to 3.5 percent of certainty equivalent consumption and depends both on the level of market debt and the output level. The highest welfare gain occurs at high market debt levels and intermediate output. The regions with high welfare gains correspond to the reduction in the sizes of the crisis and default zones as illustrated in Figure 2.4. There is only a small welfare gain in the default zone where the sovereign has no direct benefit from the shift in the bond price schedule as it defaults despite the presence of the official lending facility.

Figure 2.7: State-dependent welfare gain from the availability of financial assistance (for $h = 0$)



The state by state comparison, however, does not take into account the general equilibrium effect of living in a world with financial assistance instead of living in a world without financial assistance. To account for the general equilibrium effect, we simulate both models and weigh the state-dependent values with the endogenous probabilities of being in the according state combination. A comparison of the resulting values shows that the certainty equivalent consumption in the model with official lending facility is 0.84 percent lower than in the model without lending facility. This indicates that the negative effects of the higher default probability and higher debt service outweigh the benefits associated with financial assistance in terms of better consumption smoothing and lower borrowing costs. The international investors are not affected by the presence of the lending facility because they are risk neutral and always make zero profits in expectation due to perfect competition. There are no defaults on the bailout loans for the benchmark calibration. Therefore, the official lending facility does not incur any losses due to its lending activity, but generates profits by charging the surcharge on the riskless rate.

2.4.5 Robustness

To check the robustness of our results we vary the parameter values that govern the official lending facility, namely the strictness of the conditionality, λ, and the probability of returning to international financial markets after a default on financial assistance, θ_H. In the first column of Table 2.4 we restate the results of the benchmark calibration to facilitate comparison. In columns two and three we vary λ, while column four shows the results of changing θ_H. Our main result that the probability of default increases when financial assistance is available is robust against changes in λ and θ_H. Furthermore, the reduction of the probability of run-driven defaults and the increase of the average level of market debt are basically unaffected by the changes in λ or θ_H.

In the benchmark calibration we use a value of $\lambda = 1.01$, which is implied by the IMF program in Argentina. To evaluate the impact of the strictness we first set λ equal to one. This is equivalent to a zero deficit target as in this case no further increase of the total amount of debt is allowed when the country is borrowing from the official lending facility. Additionally, we allow for a laxer conditionality by changing λ to 1.06.[23] Increasing the strictness of the conditionality to $\lambda = 1$ results in a reduction of the use of bailout loans. There is a decrease in both the average level of financial assistance and the frequency of the use of financial assistance. As the level of market debt stays the same, the total debt level of the country slightly decreases. The stricter conditionality increases the correlation of output with the change in market debt relative to output, corr(y, $\Delta d/y$). This is because the government cannot increase its

[23]A value of $\lambda = 1.06$ corresponds to a deficit target of more than 12 percent of GDP, analogous to the calculations for the benchmark calibration in Footnote 19.

level of market debt when output is low and it is already borrowing from the official lending facility. Decreasing the strictness of the conditionality to $\lambda = 1.06$ has the opposite effect. The average levels of financial assistance and market debt and the frequency of the use of financial assistance increase. This results in a slightly higher probability of default. With laxer conditionality the government still increases its borrowing from private international investors while using financial assistance. This causes a slight reduction of the correlation of output with the change in market debt relative to output. Strict conditionality leads to higher welfare than the benchmark case and lax conditionality. Lax conditionality results in higher debt levels and a higher default probability, which is detrimental to the country's welfare.

For the benchmark calibration we employ a value of $\theta_H = 0.025$ which corresponds to an average of ten years of exclusion after a default on financial assistance. To verify to what extent our results depend on the chosen value of θ_H, we solve the model for $\theta_H = 0.0625$, which implies on average four years of exclusion after a default on financial assistance. Column four of Table 2.4 shows the resulting business cycle statistics. While the probability to default on both market debt and financial assistance is now positive, the overall probability of default remains basically unaffected. Also, the debt stocks are similar to the benchmark. Our results are therefore robust to shortening the average exclusion spell after a default on both types of debt. Defaults on both types of debt, which are present for the higher value of θ_H, imply that the government's total repayment obligations are reduced stronger than in the case of a default on market debt only. In contrast to the substantial welfare loss in the benchmark calibration we find that the country actually gains from having the financial assistance at its disposal when it faces a shorter exclusion. In comparison to the case of a longer exclusion after a default on both types of debt welfare is now about one percentage point higher. This comparatively large increase in welfare is likely to be generated by the fact that the country only defaults on both types of debt when it finds itself in an especially severe output crisis. Reducing the punishment for a complete default on both types of debt therefore increases the country's utility substantially in these cases. While the defaults on bailout loans increase the country's welfare they however also reduce the profits generated by the official lending facility.[24]

[24]For all considered parametrizations the lending facility generates positive profits.

Table 2.4: Sensitivity of the results

	benchmark	$\lambda = 1$	$\lambda = 1.06$	$\theta_H = 0.0625$
Std. dev. output	6.82	6.82	6.81	6.81
Std. dev. consumption	9.27	9.27	9.30	9.31
Std. dev. interest spread	4.56	4.62	4.58	4.88
Std. dev. trade balance	4.47	4.50	4.48	4.57
Corr(y, interest spread)	-0.41	-0.40	-0.42	-0.40
Corr(y, trade balance)	-0.31	-0.30	-0.31	-0.30
Corr(y, consumption)	0.88	0.88	0.88	0.88
Corr(interest spread, trade bal.)	0.61	0.61	0.63	0.63
Default prob. market debt	3.1%	3.1%	3.2%	3.0%
→ of which due to runs	0.90%	0.89%	0.91%	0.87%
Def. prob. market and fin. assist.	0.0	0.0	0.0	0.2%
→ of which due to runs	0.0	0.0	0.0	0.01%
Prob(h>0)	0.55	0.53	0.71	0.54
Avg. market debt (% of GDP)	45.6	45.6	45.7	45.6
Avg. fin. assist. (% of GDP)	5.3	5.2	5.9	5.1
Avg. spread market debt	3.9	3.8	3.9	3.9
Corr(y, $\Delta d/y$)	0.141	0.143	0.138	0.142
Corr(y, $\Delta h/y$)	-0.06	-0.06	-0.06	-0.06
Welfare gain due to fin. assist.	-0.84 %	-0.82%	-0.87%	0.18%

2.4.6 Comparison to related studies

Comparing our results with related findings in recent quantitative studies we find important differences. Boz (2011) and Fink and Scholl (2011) also include financial assistance into a model of sovereign default. However, both studies have a focus different to ours and do not consider the full set of channels through which financial assistance affects the probability of default in our model. The presence of an official lending facility raises average debt stocks of the government in our model. Total debt of the government increases by 16 percentage points (which is an increase of 50 percent). A rise of equilibrium debt levels is also present in the model by Fink and Scholl (2011), while Boz (2011) finds the opposite effect. In contrast to our results both studies find that the inclusion of financial assistance increases the default probability strongly. In Boz (2011) the number of defaults rises drastically from 5.8 to 64.6 per 10,000 quarters and in Fink and Scholl (2011) the default probability increases from 2.88 to 5.00 percent. One important reason for this difference is the presence of defaults due to self-fulfilling crisis in our model. The official lending facility is able to decrease the occurence of this type of default substantially. In the two other models this channel is excluded and the potential impact of bailout loans is hence restricted. Another reason for the difference might be found in the exact modeling of the official lending facility. In Boz (2011) the IFI provides unlimited amounts of non-defaultable loans to the country, which is consequently still able to smooth consumption relatively effectively after a default on market debt. This reduces the costs associated with a default relative to a version of the model without bailout loans. While there might be doubts about the commitment of the IFI to stop lending to a country in crisis, we think that our modeling choice of restricting the amounts of official lending is in line with actual policies. Roch and Uhlig (2012) consider a (basically unlimited) bailout guarantee that completely eliminates runs by private investors. In a preliminary numerical exercise they find a lower overall default probability when the guarantee is present. In difference to Roch and Uhlig (2012) in our model the government holds bailout loans in equilibrium which are senior to market debt. The associated repayment obligations affect the default incentives of the government. Considering an endogenous debt structure of both market debt and bailout loans we find that the presence of financial assistance leads to a slightly higher default probability in equilibrium.

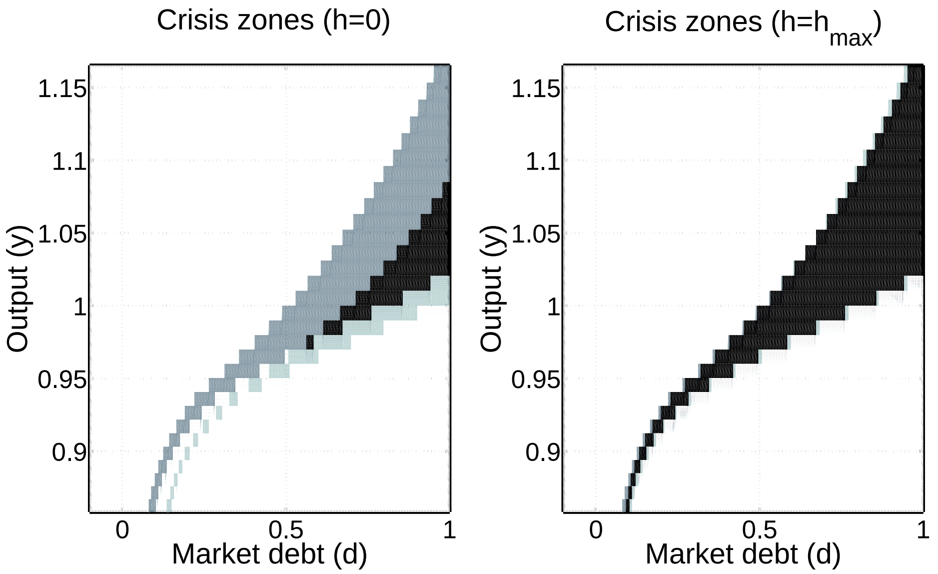
2.5 Conclusion

We construct a quantitative model of sovereign default to study the effects of the availability of financial assistance on the occurrence of defaults. The calibrated model yields business cycle statistics in line with Argentinean data. Simulating the benchmark model with financial assistance and a model version without financial assistance, we find that the presence of the official lending facility increases the probability of a default of the government on its market debt. At the same time the model version with this facility displays a higher average debt level than a model version without bailout loans. The insurance effect of bailout loans, which makes defaults less likely for a given level of debt, is therefore dominated by the general equilibrium effect of the resulting lower interest rates. The shift in the bond price schedule leads to higher equilibrium debt levels of the government and makes defaults again more likely. While the official lending facility is successful in reducing the number of defaults that are caused by runs of the investors it does not reduce the overall default probability. These results are robust against variations in the strictness of the conditionality and shortening the average exclusion spell after a default also on bailout loans. A welfare comparison shows that certainty equivalent consumption is lower in the model with financial assistance than in the model without financial assistance. Stricter conditionality leads to a higher welfare than lax conditionality as it results in lower total debt levels. The presence of financial assistance leads to an increase in welfare only when the punishment after a default on both types of debt is sufficiently weak such that the country sometimes chooses to default also on bailout loans. The recent increase in official lending underscores the importance of understanding its impact on default incentives and welfare. Our results suggest that, while financial assistance can help to avoid defaults in the short run, it might entail substantial unintended consequences in the long run.

Appendix to Chapter 2

2.A Comparison of crisis zones

Figure 2.8: Comparison of crisis zones



Notes: black areas: zones overlap, grey areas: crisis only when no financial assistance is available, bright grey areas: crisis zone only in the model with financial assistance.

Chapter 3

Devaluation and Sovereign Default

3.1 Introduction

Ten years after establishing a currency board in 1991 the Argentinean government defaulted on its debt in 2001. The establishment of the currency board deprived the government of the option to devalue its currency to reduce the real debt burden and might therefore have been an important driver of the default. This chapter sets up a model to analyze how the possibility to devalue the currency to lower the real debt burden affects average debt levels and the default probability of borrowing sovereigns.

Pegging the exchange rate can help to reduce inflation rates as it constrains monetary policy (Barro and Gordon, 1983). When the government borrows abroad in domestic currency, pegging the exchange rate can also help to lower sovereign spreads as credibly pegging the currency eliminates devaluation risk. However, a government that pegs the currency loses the flexibility to reduce the real value of its debt burden via a devaluation in the case of adverse shocks. Additionally, lower sovereign interest rates might induce the government to increase its debt, which in turn might raise default incentives.[1]

The analysis is conducted in a quantitative model of sovereign default. The government borrows in domestic currency from foreign investors. This provides the government with the option to reduce the real value of its debt via a devaluation of the currency. A devaluation, however, causes a temporary deterioration of the terms of trade and in this way reduces the consumption possibilities of households. The

[1]The advantages and disadvantages of pegging the exchange rate have been discussed extensively in the literature. Pegging the exchange rate can for example help to increase trade by eliminating currency risk (Alesina and Barro, 2002). The present analysis abstracts from these potential benefits of pegging the exchange rate to isolate the impact of a fixed exchange rate on debt and default dynamics.

government faces a trade-off between using labor taxes or devaluing. A devaluation relaxes the budget constraint of the government and makes it possible to reduce labor taxes in comparison to the level of labor taxes that would be necessary without devaluation. The positive impact of a reduction of labor taxes on labor supply and output, however, differs depending on the level of productivity. When productivity is high labor supply is already very high and a reduction of labor taxes increases labor supply only slightly. At lower levels of productivity a reduction of labor taxes has a stronger positive impact on labor supply. Therefore, a negative relationship between the level of productivity and the devaluation incentives of the government emerges. Simulations of the model show that at low productivity levels the government optimally chooses an outright default on its debt (and no devaluation), while at intermediate productivity levels the government devalues to reduce its debt burden and to lower labor taxes. When productivity is currently high there are no defaults and devaluation incentives are the smallest. The optimal degree of devaluation also depends on current debt levels. When debt levels are high the government devalues stronger to avoid higher labor taxes that would result from servicing its debt without devaluing.

The model considered for the analysis builds on the standard sovereign default models by Eaton and Gersovitz (1981) and Arellano (2008). In this framework a default by the government entails some cost and the government optimally decides whether to default on its outstanding debt stock. While these two papers consider endowment economies, the analysis of this chapter is conducted in a production economy following Cuadra, Sanchez, and Sapriza (2010). It is important to consider a production economy as the impact of a devaluation affects households to a different degree depending on the current level of productivity due to the trade-off between labor taxation and devaluation. In case of an endowment economy this trade-off does not exist and a devaluation would affect households almost identically independent of the current level of output. In this case there would be no devaluations in equilibrium.[2]

The model is calibrated to Argentinean data for the time period before the estab-

[2]To generate devaluation in equilibrium the devaluation decision needs to depend on current productivity. In this case the government can build up debt while productivity is high and devalues when productivity falls. When the government devalues independent of current productivity the bond price collapses as the government approaches debt levels at which it starts to devalue. In this case, in equilibrium the government would never choose debt levels which imply a devaluation.

lishment of the currency board in 1991. To assess the impact of the option to devalue on average debt levels and the default probability, the benchmark model is compared with a model version in which the option to devalue is eliminated. Simulations of the two models show that average debt is higher when the government cannot devalue. The elimination of the devaluation option, however, also increases the default probability. This is due to both higher average debt levels and a lower flexibility when facing sovereign debt crisis as the option to devalue to lower the value of the debt burden is not existent anymore. The results of this chapter also shed light on the debate about the 'original sin'. Eichengreen and Hausmann (1999) refer to the 'original sin' as being the inability to borrow abroad in terms of domestic currency.[3] When the government has the option to devalue its debt, sovereign spreads at low government debt levels are higher due to the devaluation risk. The higher borrowing costs endogenously reduce government debt levels. The government therefore borrows on average less from international investors when the debt is denominated in domestic currency than when the debt is denominated in foreign currency.

Several papers that consider nominal government debt within a model of sovereign default are based on the model of self-fulfilling debt crises of Cole and Kehoe (2000). Da-Rocha, Giménez, and Lores (2012) analyze the devaluation decision of a government that borrows in foreign currency and is faced with self-fulfilling runs by foreign investors. Expectations of a devaluation make households reduce domestic capital holdings and increase the incentive for the government to devalue. Aguiar, Amador, Farhi, and Gopinath (2013) provide a continuous time model of nominal debt to study the impact of inflation credibility on the occurrence of self-fulfilling crises. The authors model the degree of commitment to low inflation by a utility cost for inflation and find that an intermediate inflation credibility minimizes the exposure to rollover risk. This chapter is also related to Araujo, Santos, and Leon (2013) who extend the model of Cole and Kehoe (2000) to calculate welfare gains from issuing government debt denominated in domestic instead of foreign currency. The authors determine in which way the optimal currency regime depends on refinancing risk and inflation risk. All three papers mentioned above analyze how the option to inflate affects the default decision of the government when faced with runs by international investors. The focus of this chapter is different as it investigates how the

[3]The 'original sin' is also sometimes referred to as the inability to borrow long-term domestically.

option to devalue affects the default probability of the government when it is faced with fundamental shocks as in Arellano (2008). In contrast to the mentioned papers which model the cost of a reduction of the real value of the debt burden by inflation as being exogenous, in this chapter the cost of devaluation is modeled explicitly via a temporary deterioration of the terms of trade which negatively affects the consumption possibilities of domestic households. The model endogenously generates defaults and devaluations in equilibrium.

This chapter is also related to Arellano and Heathcote (2010) who study the impact of dollarization in a model in which the government faces stochastic output and taste shocks. A dollarization implies renouncing monetary policy, thereby making access to international debt markets more valuable which helps to loose borrowing constraints. A further related study is Röttger (2013) who investigates within a closed economy model the impact of a possible government default on average inflation rates, sovereign debt levels and welfare. The author finds that sovereign risk premia reduce average debt levels. Lower debt levels increase welfare and reduce the incentive to implement high inflation rates.

The rest of this chapter is organized as follows: Section 3.2 describes the benchmark model. Section 3.3 discusses the calibration of the model and briefly describes the employed solution method. Section 3.4 presents the results of the quantitative analysis and Section 3.5 concludes.

3.2 Model

The analysis is set in a small open economy with an infinite time horizon building on Cuadra et al. (2010). The government decides on debt issuance, default and devaluation policies, labor taxes and government spending to maximize the utility of the households that live in the small open economy. Households consume a domestic and a foreign tradable good. The government trades bonds denominated in domestic currency with foreign investors on international financial markets. A devaluation of the domestic currency causes a temporary deterioration of the terms of trade as prices are assumed to adjust with a time lag. The deterioration of the terms of trade makes foreign tradable goods relatively more expensive and reduces the consumption possibilities of households who trade part of the domestic tradable good for the foreign tradable good given the terms of trade. At the same time a devaluation triggers a higher inflation rate until the end of the period and thereby decreases the debt burden of the government, providing a second policy instrument next to an outright default on the outstanding debt.

3.2.1 Households

The preferences of the representative household of the small open economy are given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t u \left(c_{H,t}, c_{F,t}, g_t, 1 - l_t\right), \tag{3.2.1}$$

where $\beta \in (0, 1)$ is the discount factor and E_0 is the expectation operator. The period utility function $u(\cdot)$ is strictly increasing and strictly concave in its arguments and hence implies risk aversion. Private consumption of domestic tradable goods is denoted by $c_{H,t}$, while $c_{F,t}$ is private consumption of foreign tradable goods. Public spending is represented by g_t and l_t is the amount of time allocated to the production of domestic tradable goods in period t.

Output is produced with labor input l_t according to the production technology $F(l_t)$ and is subject to productivity shocks:

$$y_t = A_t F(l_t), \tag{3.2.2}$$

where productivity A_t follows a Markov process. Given the terms of trade households optimally decide about consumption of domestic and foreign tradables. Next to choosing consumption households also decide about labor supply.

The households' budget constraint is

$$c_{H,t} + \frac{1}{\tau_t(d_t)} c_{F,t} = (1 - T_t) A_t F(l_t), \tag{3.2.3}$$

where T_t is the labor tax and τ_t are the terms of trade which depend on the devaluation decision d_t of the government. As households derive utility both from domestic tradable goods, $c_{H,t}$, and foreign tradable goods, $c_{F,t}$, they trade part of the produced domestic tradables in exchange for foreign tradables. Households can exchange domestic for foreign goods at the rate implied by the terms of trade. From the household's first order conditions, one can derive the following equations for the optimal levels of consumption of households:

$$-\frac{u_l(c_H, c_F, g, 1-l)}{u_{c_H}(c_H, c_F, g, 1-l)} = (1-T)AF_l(l), \tag{3.2.4}$$

$$-\frac{u_l(c_H, c_F, g, 1-l)}{u_{c_F}(c_H, c_F, g, 1-l)} = (1-T)AF_l(l)\tau(d), \tag{3.2.5}$$

where u_l, u_{c_F} and u_{c_H} denote the marginal utility of labor, consumption of foreign trdables and consumption of domestic tradables, respectively, and F_l denotes the marginal product of labor.

3.2.2 Decision problem of the government

In each period the benevolent government of the small open economy maximizes the discounted sum of the household's utility by deciding about the following: First, the government decides about the borrowing of the country. Second, the government can decide to default or to devalue.[4] Last, the government sets labor taxes and decides about optimal government spending.

Government bonds are denominated in domestic currency and have a maturity of one period.[5] In each period the government optimally decides whether to repay its debt or to default on its repayment obligations. Next to the default decision the government can also devalue the country's currency.[6] A default on government bonds leads to exclusion from international financial markets and entails an exogenous output cost. A devaluation avoids the cost of an outright default. However, it is assumed that following a devaluation of the domestic currency domestic prices do not adjust immediately. Therefore, a nominal devaluation temporarily causes a real devaluation and the terms of trade temporarily deteriorate to the same extend[7]:

[4]To simplify the model it is assumed that the government can devalue the exchange rate but not revalue it.

[5]One period bonds are also used e.g. by Arellano (2008) and Da-Rocha et al. (2012). Chatterjee and Eyigungor (2012) and Hatchondo and Martinez (2009) analyze long term loans with a fixed maturity.

[6]The assumption that the government can deliberately choose to devalue can be rationalized by the observation that in many developing economies there is only limited central bank independence.

[7]The initial τ_0 is assumed to be predetermined and to be equal to 1.

$$\tau_t(d_t) = \frac{1}{1+d_t}, \tag{3.2.6}$$

where d_t is the degree of devaluation chosen by the government. The assumption that prices adjust with a time lag is in line with empirical observations by Borensztein and De Gregorio (1999) who show that devaluations usually have a very low initial pass-through on inflation.[8] The deterioration of the terms of trade cause a reduction of the consumption possibilities of the households. Prices are assumed to adjust until the end of the period such that a nominal devaluation causes an according inflation until the end of the period and has no effect on next period's terms of trade.[9] Government debt is denominated in domestic currency and rolled over at the end of the period after prices have adjusted. A devaluation therefore leads to a reduction of the real value of outstanding government debt. In equilibrium, both the possibility of a default on government bonds and the possibility of a devaluation increase sovereign risk spreads as international investors demand a compensation for the default and the devaluation risk (see Section 3.2.3).

When the government decides to repay its debt it faces the following budget constraint in real terms[10]:

$$g_t = T_t A_t F(l_t) + q_t(b_{t+1}, A_{t+1}) b_{t+1} - \frac{b_t}{1+d_t}, \tag{3.2.7}$$

where b_t denotes real government debt and $q_t(b_{t+1}, A_{t+1})$ is the price the government receives for newly issued government bonds.

The government budget constraint in real terms implies that the government borrows in units of domestic tradables. Based on Da-Rocha et al. (2012) it is assumed that there is a technology that transforms foreign tradable goods into domestic tradable goods. According to the timing of the model the government borrows at the end of the period when the terms of trade are always 1 which implies that the technology transforms one unit of the foreign good into one unit of the domestic good

[8]Da-Rocha et al. (2012) provide evidence for the impact of the Argentinean devaluation at the beginning of 2002. The authors find that the nominal devaluation led to a real devaluation of nearly the same extend in the first months after the devaluation.

[9]Goldfajn and Werlang (2000) show that the impact of a devaluation on inflation increases over time.

[10]For the government budget constraint in nominal terms and the relation to the government budget constraint in real terms see Appendix 3.A.

at the end of each period.[11]

The government's choice between the different options depends on the respective consequences. As it is commonly assumed in the literature, an outright default always occurs on the full amount of outstanding debt.[12] After a default, the country is excluded from international financial markets for a limited time and suffers from lower productivity $h(A) \leq A$ as long as it is excluded from financial markets.[13] A country that has defaulted on its debt regains access to financial markets with a constant probability θ.

The value function of being in good credit-standing $V^o(b, A)$ depends on the amount of outstanding debt and the productivity state. It is given by the maximum of the value of repayment and the value of default:

$$V^o(b, A) = \max\Big\{V^c(b, A), V^{def}(A)\Big\}, \tag{3.2.8}$$

with V^c being the value function of repayment. In this case the country fulfills its contractual obligations, i.e. it pays back its outstanding debt, and chooses the optimal level of new debt. V^{def} is the value function of defaulting on the outstanding debt and consequently continuing without access to international financial markets. The government takes into account the optimal response of households when deciding about taxes, government spending, borrowing, default and devaluation.

The value function of debt repayment, V^c, is given by:

$$V^c(b, A) = \max_{\{g,T,b',d,c_H,c_F,l\}} \Big\{u\Big(c_{H,t}, c_{F,t}, g_t, 1 - l_t\Big) + \beta \int_{A'} V^o(b', A')\, f(A', A)\, dA'\Big\}, \tag{3.2.9}$$

[11] There are two reasons why a technology that allows to transform the goods might exist: First, the small open economy might not be the only producer of the domestically produced tradables. Second, households trade domestic tradables for foreign tradables in every period such that the foreign investors have a stock of domestic tradables in every period.

[12] Exceptions include Benjamin and Wright (2009) and Yue (2010) who consider haircuts in models of debt renegotiation.

[13] For a discussion of the empirical evidence see Panizza, Sturzenegger, and Zettelmeyer (2009).

subject to

$$
\begin{aligned}
& g = TAF(l) + q(b,A)b' - \frac{b}{1+d}, \\
& c_H + \frac{1}{\tau(d)} c_F = (1-T)AF(l), \\
& -\frac{u_l(c_H, c_F, g, 1-l)}{u_{c_H}(c_H, c_F, g, 1-l)} = (1-T)AF_l(l), \\
& -\frac{u_l(c_H, c_F, g, 1-l)}{u_{c_F}(c_H, c_F, g, 1-l)} = (1-T)AF_l(l)\tau(d),
\end{aligned}
$$

where $f(A', A)$ denotes the transition probability to productivity state A' in the next period given productivity state A in the current period (next period's variables are indicated by a prime).

If the government decides to default, it does not repay its debt and hence relaxes its budget constraint. However, a default entails a temporary exclusion from international financial markets and a temporary fall of productivity. The value function associated with a default on market debt, V^{def}, is given by:

$$
\begin{aligned}
V^{def}(A) = \max_{\{g,T,d,c_H,c_F,l\}} & \Bigg\{ u\left(c_{H,t}, c_{F,t}, g_t, 1-l_t\right) \\
& + \beta \int_{A'} \Big[\theta V^o(0, A') + (1-\theta) V^{def}(A') \Big] f(A', A)\, dA' \Bigg\},
\end{aligned}
\tag{3.2.10}
$$

subject to

$$
\begin{aligned}
& g = T\ h(A)F(l), \\
& c_H + \frac{1}{\tau(d)} c_F = (1-T)h(A)F(l), \\
& -\frac{u_l(c_H, c_F, g, 1-l)}{u_{c_H}(c_H, c_F, g, 1-l)} = (1-T)h(A)F_l(l), \\
& -\frac{u_l(c_H, c_F, g, 1-l)}{u_{c_F}(c_H, c_F, g, 1-l)} = (1-T)h(A)F_l(l)\tau(d).
\end{aligned}
$$

In this case the country has zero market debt due to its default. The value function

V^{def} is therefore independent of b. With probability θ the country can return to international financial markets in the next period.

3.2.3 International investors

International investors act in perfectly competitive markets and can borrow and lend at world financial markets at a risk-free interest rate r. The investors are assumed to be risk neutral.[14] Profit maximization implies the following bond price equation, which ensures zero profits in expectation:

$$q_t\left(b_{t+1}, A_t\right) = E_{A_{t+1}|A_t}\left[\frac{1-\delta\left(b_{t+1}, A_{t+1}\right)}{(1+r)(1+d\left(b_{t+1}, A_{t+1}\right))}\right]. \tag{3.2.11}$$

The investors price the bond by forming expectations over next period's productivity A_{t+1} which, along with the government debt level b_{t+1}, influences the default decision $\delta\left(b_{t+1}, A_{t+1}\right)$ and the devaluation decision $d\left(b_{t+1}, A_{t+1}\right)$. As productivity is assumed to follow a Markov process, expectations about next period's productivity are formed conditional on the current productivity. The indicator variable δ denotes the default decision of the government in the next period. If the government defaults on its debt, δ takes a value of one. If there is no default, δ equals zero. Similarly, if the government does not devalue d equals zero. If the government devalues its currency, d takes a positive value according to the degree of devaluation, i.e. $d > 0$. Anticipating the government's default and devaluation decision, the investors take into account the probability of a default or devaluation for a given choice of b_{t+1} and adjust the bond price accordingly. The equilibrium interest rate on sovereign debt held by international investors hence rises with the risk of a default and devaluation as the investors demand a premium for compensation.

Definition: A recursive equilibrium for this small open economy is defined as:

1. a set of policy functions for household's consumption of domestic tradables c_H and foreign tradables c_F and household's labor supply l,

[14]For a model of sovereign default with risk averse lenders see Lizarazo (2013).

2. a set of policy functions for government expenditures g, labor taxes T, issuance of government debt b, default decisions δ and devaluation decisions d,

3. a bond price function q,

4. a set of value functions V^o, V^c, V^{def}

   such that

   a) given the government policies and the bond price function, the household policies for consumption and labor solve the household problem,

   b) given the bond price function and the optimal policies of households, the value functions V^o, V^c and V^{def} and the government's policy functions g, T, b and the government's default and devaluation decisions solve (3.2.8), (3.2.9) and (3.2.10),

   c) the equilibrium bond price function q fulfills (3.2.11) such that risk-neutral international investors earn zero expected profits.

3.3 Calibration

As the model is solved numerically, functional forms and parameter values have to be chosen. The parameter values are set in line with previous literature or to match certain moments of the data. The model is calibrated to Argentinean data from 1970 till 1979 as Argentina maintained a flexible exchange rate in this decade and borrowed from foreign investors.[15] While Argentina also had a flexible exchange rate in the 1980s, two government debt restructurings in 1982 and 1989 and prolonged renegotiations with foreign creditors between the two defaults were accompanied by periods of exclusion from international financial markets. The model is calibrated to the time period before 1980 that is not affected by an unsettled government default. Before the establishment of the currency board, Argentina faced periods of high inflation coupled with substantial devaluations of the Argentinean Peso. This makes this time period especially attractive for the calibration of the model. The parameter values of the benchmark calibration are stated in Table 3.1.

[15] Before the establishment of the currency board the majority of Argentinean debt was denominated in domestic currency (see Damill, Frenkel, and Rapetti, 2005).

The utility function of households is assumed to be of the GHH form:

$$u(c_H, c_F, g, 1-l) = \gamma \left(\frac{g^{1-\sigma}}{1-\sigma} \right) + (1-\gamma) \left(\frac{\left(c_H^{\phi} c_F^{1-\phi} - \chi \frac{l^{1+\psi}}{1+\psi} \right)^{1-\sigma}}{1-\sigma} \right). \tag{3.3.1}$$

GHH preferences help to match business cycle moments in open economy models and simplify the supply side of the model (Mendoza and Yue, 2012). The coefficient of relative risk aversion, σ, is set to 2 which is a standard value in the literature. Following Mendoza (1991) and Fink and Scholl (2011), ψ is assumed to take a value of 0.455, implying a labor supply elasticity of $\frac{1}{\psi} = 2.2$ which is a value typically used for small open economy models. The disutility of labor χ is chosen to match the same average labor supply as in Cuadra et al. (2010) and the weight of government consumption γ is set to match the average ratio of public spending to private consumption. The exponent of consumption of foreign tradables $1-\phi$ is set to match the share of imported goods and services in the Argentinean economy.[16] Following Cuadra et al. (2010) production is assumed to be linear in labor: $F(l) = l$.

A default entails an asymmetric output cost that is modeled as in Arellano (2008):

$$h(A) = \begin{cases} \eta E(A) & \text{if } A > \eta E(A) \\ A & \text{if } A \leq \eta E(A), \end{cases} \tag{3.3.2}$$

with $\eta \in (0,1)$. The state-dependence of the output cost function induces a strong relation between the default decision and the output level. The output costs are needed to generate a sufficient number of defaults in equilibrium as in this case the government builds up debt when productivity is high and defaults when productivity drops. The parameter of the cost of default η is set to match the average default frequency of the Argentinean economy for the time periods during which Argentina had a floating exchange rate regime. The calculation of the default probability is based on data by Bordo, Eichengreen, Klingebiel, and Martinez-Peria (2001) who classify the currency regimes of 21 countries for the last century. According to this classification scheme Argentina had a floating exchange rate regime during 64 years of the century lasting from 1898 till 1997. During the same time, based on

[16] The data for average public spending and consumption of foreign tradables is taken from the World Bank's Global Development Finance Database.

the default and rescheduling events documented by Reinhart and Rogoff (2009), Argentina experienced two default episodes in the 1950s and 1980s yielding an overall default probability of 3.1%.

Log productivity follows an AR(1) process:

$$\ln(A_t) = \rho \ln(A_{t-1}) + \epsilon_t, \tag{3.3.3}$$

with $\epsilon_t \sim \mathcal{N}(0, \sigma_\epsilon^2)$. The parameters of the process for productivity are set as in Fink and Scholl (2011) to match the autocorrelation and standard deviation of the Argentinean real GDP series.[17]

Table 3.1: Calibration

Parameter		Value	Target/Source	Value
Risk aversion	σ	2	Literature	
Labor elasticity	$\frac{1}{\psi}$	2.2	Literature	
Disutility of labor	χ	0.69	Avg. labor supply	0.71
Weight government cons.	γ	0.365	Avg. ratio g/c	15.7%
Weight cons. foreign trad.	$1-\phi$	0.12	Avg. ratio c_F/GDP	6.2%
Default cost	η	0.97	Default probability	3.1%
Autocorrelation $\log(y_t)$	ρ	0.85	Argentinean Data	
Std. dev. output shock	σ_η	0.0138	Argentinean Data	
Discount factor	β	0.88	Debt service (% of GDP)	6.8
Risk-free rate	r	0.01	Literature	
Prob. of reentry	θ	0.125	Avg. exclusion length	2 years

The discount factor β is set to match the average ratio of government debt service to quarterly GDP. As in to the majority of models of sovereign default the discount factor is relatively low which is often interpreted as reflecting a strong impatience of the government.

The Argentinean debt service is computed using annual data from the World Bank's Global Development Finance Database. One has to transform the annual data as the model is calibrated at quarterly frequency. At yearly frequency the average debt service on debt held by private international investors in the years from 1970 to 1979 is 1.7 percent of GDP. This implies a quarterly value of approximatively 6.8 percent.

[17] Due to limited data availability the productivity process is estimated based on the Argentinean GDP series for 1993 till 2010. There is no quarterly GDP data for the pre-1980 period.

The risk-free rate is set to one percent per quarter, which implies an annual real rate of roughly four percent, a standard value in the real business cycle literature. The reentry probability after a default, θ, is based on estimates of Gelos, Sahay, and Sandleris (2011). The authors report short periods of exclusion from international financial markets after a default. The estimate used for θ in the calibration is consistent with the median duration of exclusion after a sovereign default in the 1990s which was two years.

The model is solved by value function iteration following the procedure described in Appendix 3.B. The log productivity process is discretized with the Tauchen algorithm using 25 grid points. The mean of the log productivity process is set to zero. For the dimension of government debt an equally spaced grid of 100 points is used that spans the asset space from zero debt to 40 percent debt relative to a quarterly output of unity. For the devaluation the grid spans possible devaluations from zero devaluation to 320 percent devaluation using 50 grid points.

3.4 Results

This section presents the results of the quantitative analysis of the model. First, the model is simulated and business cycle statistics are calculated to assess the performance of the model. Next, the impact of the possibility to devalue is determined by comparing the benchmark model with the same model without the option to devalue. In a last step, the dynamics of the model are illustrated by presenting several policy functions and model simulations.

3.4.1 Business cycle statistics

Table 3.2 shows the business cycle statistics of the model and for comparison also provides the corresponding statistics from Argentinean data.[18] The business cycle statistics show that the model matches key aspects of the data[19]: Consumption has a

[18]The model is simulated 200 times for 1000 quarters. To compare the results of the model with the data, default and exclusion periods are dropped from the model simulation. Additionally, similar to Chatterjee and Eyigungor (2012), two years after redemption are excluded as the country counterfactually returns to financial markets with zero debt.

[19]The model performance (with respect to the standard deviations and correlations) is assessed based on quarterly Argentinean data from Argentina's Ministry of Economics and Finance (MECON) for

higher volatility than output and all of the correlations have the correct signs. Public and private consumption show a strong co-movement with output, while the interest rate spread, the trade balance and labor taxes are countercyclical. The median devaluation in periods in which a devaluation occurs is 12 percent and therefore lower than in the data.[20] While there is a high probability of devaluation in the data, the model delivers only a relatively small probability of devaluation. The reasons for the low devaluation probability will be discussed in Section 3.4.3.

Table 3.2: Business cycle statistics

Variable	Benchmark model	Data
Std. dev. output	6.2	4.1*
Std. dev. total private consumption	6.6	4.7*
Std. dev. public consumption	7.8	2.2*
Std. dev. interest rate spread	3.8	8.3*
Std. dev. trade balance	0.9	1.6*
Std. dev. tax	0.6	2.0*
Corr(output, interest rate spread)	-0.48	-0.69*
Corr(output, trade balance)	-0.65	-0.91*
Corr(output, total private consumption)	0.99	0.98*
Corr(output, public consumption)	0.98	0.59*
Corr(output, tax)	-0.62	-0.41*
Default probability	3.1%	3.1%
Prob. of devaluation	1%	38%
Avg. debt service (% of GDP)	6.8	6.8**
Median devaluation (d>0)	12%	23%**
Avg. spread	0.04	0.08*
Avg. gov. spend./total private cons. (in %)	15.7	15.7**
Avg. cons. foreign tradables/output (in %)	10.3	6.2**

Notes: Trade balance in percent of GDP. Spreads are calculated relative to the 3-month U.S. Treasury bills (data from FRED). Based on data availability calculations are for 1993-2010 (*) and 1970-1979 (**). To calculate the standard deviations and correlations of the variables the series are detrended with the Hodrick-Prescott filter applying a smoothing parameter of 1600. Data for the probability of devaluation and the median devaluation are based on Reinhart and Rogoff (2009) and Bordo et al. (2001): From 1898 till 1979 Argentina was in a floating exchange rate regime for 52 years and devalued by at least 15% in 20 of the 52 years.

1993 till 2010 because for several variables no quarterly data is available for the pre-1993 period.

[20] The median devaluation is considered rather than the average devaluation as few periods of hyperinflation strongly influence the average devaluation in the data.

3.4.2 Effect of devaluation option

To investigate the impact of the possibility to devalue on average debt levels and the default probability, the benchmark model is compared to a version of the model without the option to devalue (which corresponds to the case of a country within a currency union, a country with a currency board or an economy that borrows in foreign currency). Table 3.3 compares the resulting statistics of both models. The default probability, the average debt level and the average spread are lower in the benchmark model than in the model without the devaluation option. A devaluation provides the government with a second possibility to reduce the real value of its debt burden. At low government debt levels the resulting equilibrium sovereign interest rates increase more strongly with government debt in the benchmark model. Higher spreads induce the government to reduce its average debt holdings, thereby reducing the average default probability. When the possibility to devalue does not exist, at low government debt levels sovereign risk spreads (for a given level of debt) are lower and the government chooses higher average debt levels. Higher debt levels in turn increase the default probability and average spreads. Additionally, in the benchmark model the government sometimes prefers to devalue instead of an outright default which also reduces the default probability. In total, the default probability is 3.1 percent in the benchmark model and increases to 3.5 percent when the government cannot devalue its debt.

Table 3.3: Impact of devaluation option

Variable	Benchmark model	Model w/o deval.
Default probability (in %)	3.1	3.5
Avg. debt service (% of GDP)	6.8	7.1
Avg. spread (in %)	3.7	4.2
Avg. cons. of foreign trad. (% of GDP)	10.3	10.4

Notes: As the model features one period debt, the average debt service coincides with the average debt level.

The simuations show that eliminating the possibility to devalue leads to a higher average debt service which is in line with Argentinean data where the average debt service increased after the introduction of the currency board.[21] Furthermore the

[21]The average Argentinean debt service from 1970-1979 was 6.8% of GDP (benchmark calibration)

increase in the spreads is in line with evidence by Jahjah, Wei, and Yue (2012) who find higher sovereign bond spreads for countries with less flexible exchange rate regimes for a sample of 42 developing countries.[22] A further result of the model is that without the option to devalue average levels of consumption of foreign tradables increase. Foreign tradables become relatively cheaper in the absence of devaluations as in this case the terms of trade are constant. The increase in consumption of foreign tradables is in line with Argentinean data as average consumption of imported goods and services increased from 6.2% to 10.4% after the establishment of the currency board.[23]

3.4.3 Model dynamics and model simulation

To provide intuition for the model dynamics several policy functions are examined. The model preserves important features of standard models of sovereign default. Figure 3.1 depicts the default and devaluation decision of the government depending on current debt and productivity. Higher levels of debt make a default more attractive for the government as the gain from defaulting is increasing with debt levels while the cost of default is independent of the amount of government debt. Similarly, higher government debt levels also make a devaluation more attractive for the government. In line with standard models of sovereign default, the default decision also depends on current productivity. Repaying a given amount of debt has different consequences for public and private consumption depending on current productivity. Given low productivity output is below average and repaying a given amount of debt leads to lower public and private consumption than when productivity and output are high. Default incentives are therefore stronger when productivity is low. In line with data

and 11.6% during the time of the currency board. Even when including the 1980s into the pre-currency-board average the resulting average debt service of 10.3% is still lower than the average during the time of the currency board.

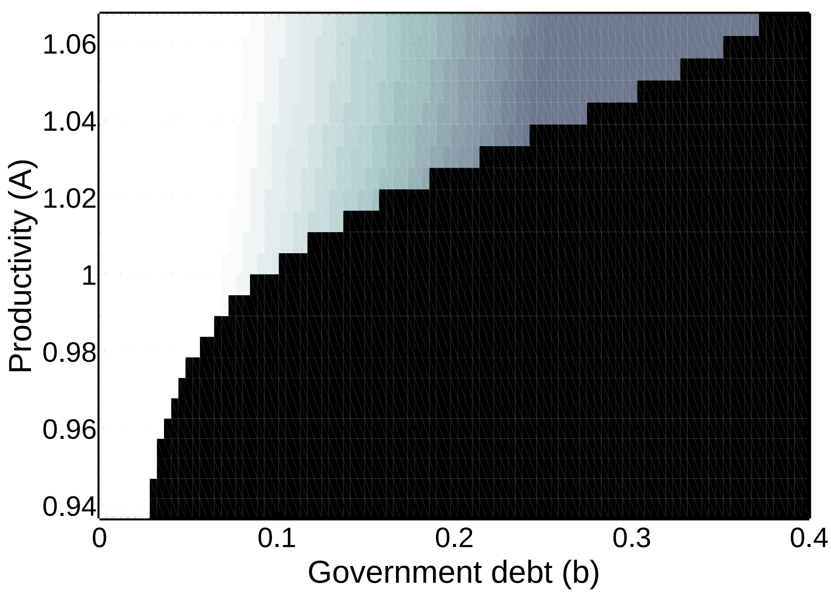
[22] As there is no data for Argentinean sovereign bond spreads for the pre-1980 period, there is no direct way of comparing sovereign bond spreads in Argentina before and after the introduction of the currency board.

[23] The increase in the consumption of foreign tradables after the elimination of the option to devalue is smaller in the model than in the data because the probability of a devaluation in the benchmark model is small. The impact of a terms of trade deterioration on consumption of foreign tradables can be assessed by comparing the average consumption of foreign tradables in periods with devaluation and periods without devaluation in the benchmark model: Consumption of foreign tradables is 14.7% lower in periods with devaluation.

from historical default events (see Tomz and Wright, 2007) defaults in the model occur when output is below average.

At higher debt levels the government prefers to devalue instead of defaulting when productivity is above average. From the perspective of the government a devaluation has the advantage that it avoids an exclusion from international financial markets and the government can continue to borrow in the next periods. The chosen degree of devaluation depends both on current productivity and current debt levels. A devaluation causes a temporary deterioration of the terms of trade and in this way reduces the consumption possibilities of households. Due to this cost the government does not devalue when debt levels are low. A devaluation relaxes the budget constraint of the government and thereby allows the government to reduce labor taxes. The government therefore faces a trade-off between using labor taxes or devaluing.

Figure 3.1: Default and devaluation regions



Notes: white region: no default and no devaluation, black region: default and no devaluation, grey region: no default and devaluation (higher degrees of devaluation are marked by darker grey). The maximum devaluation is 320%.

When debt levels are high the government devalues stronger as this relaxes the government budget constraint to a larger degree. This allows the government to avoid higher labor taxes that would result from servicing its debt without devaluing. Next to the government debt level, the current level of productivity also determines the optimal choice of devaluation as the positive impact of a reduction of labor taxes on labor supply and output differs depending on the level of productivity. When productivity is high labor supply is already very high and a reduction of labor taxes increases labor supply only slightly. At lower levels of productivity a reduction of labor taxes has a stronger positive impact on labor supply. Therefore, a negative relationship between the level of productivity and the devaluation incentives of the government emerges.[24] To generate a high probability of devaluation a strong relation between the devaluation decision and the productivity level is needed. In this case the government can accumulate high levels of debt while productivity is high and reduce the debt burden with devaluations when productivity falls. For the elasticity of labor supply chosen in the benchmark calibration the model produces only a weak relation between the devaluation decision and productivity. This is the main reason why the devaluation probability in the model simulations reported in Table 3.2 is lower than in the data.[25]

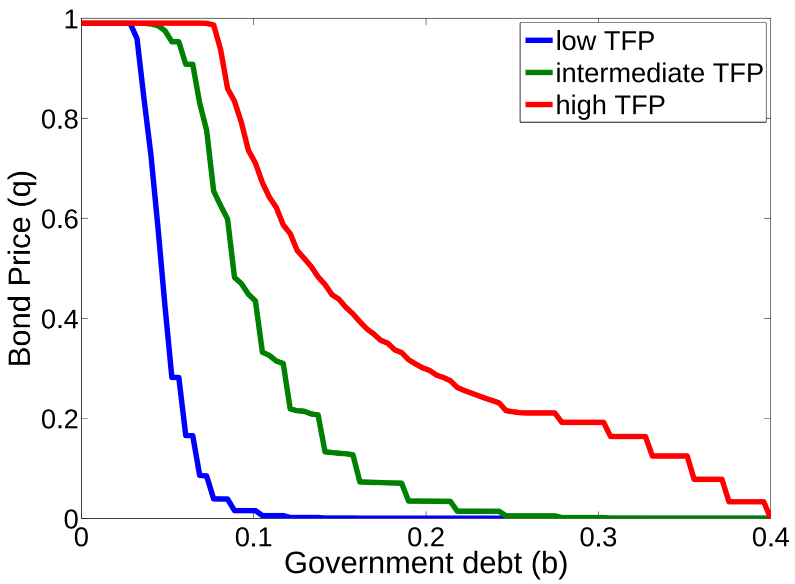
Figure 3.2 shows the equilibrium bond price schedule which reflects the default and devaluation decisions of the government. At low levels of debt the government prefers to repay instead of devaluing or defaulting. Therefore, the government can borrow at the riskless rate when debt levels are low, while bond prices fall to zero for high debt levels at which the government defaults for sure. As the government defaults more when productivity is low than when productivity is high the equilibrium bond price is positively correlated with productivity.

The devaluation decision of the government also influences the bond price schedule in Figure 3.2 as a devaluation corresponds to a partial default from the point of view of the international investors who hold the bonds. At low productivity, the government does not devalue and either repays its debt or defaults. This leads to the strong decline of the bond price with increasing government debt levels. At

[24] In the case of completely inelastic labor supply, the optimally chosen degree of devaluation is nearly independent of productivity. In this case in equilibrium no devaluation is possible as the government always chooses debt levels that are below the level at which a devaluation occurs. This is due to the fact that foreign investors anticipate the devaluation decision of the government and demand spreads that are prohibitively high.

[25] Choosing a higher elasticity of labor supply increases the relation between the devaluation decision and productivity and results in a higher devaluation probability but comes at the cost of a counterfactually high variance of labor supply.

Figure 3.2: Bond price schedule

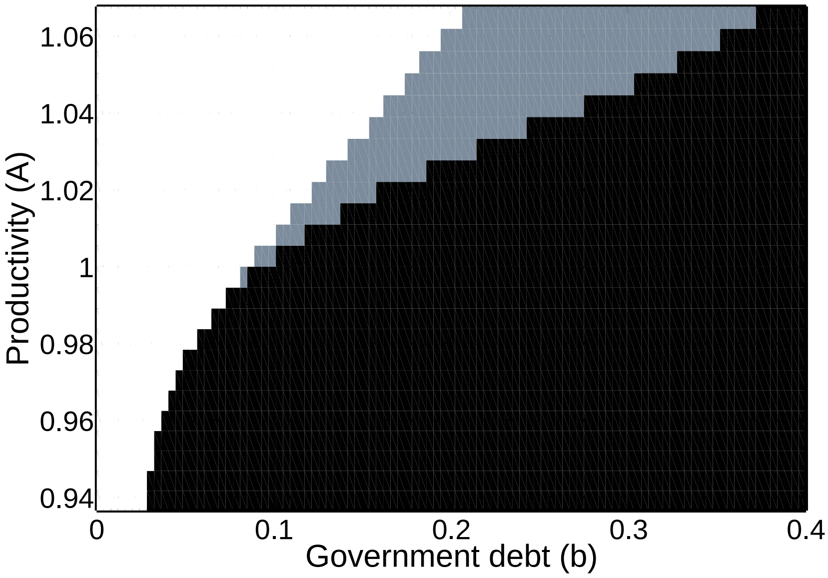


high productivity the government first devalues at intermediate debt levels and only defaults for very high debt levels. This leads to the less pronounced decline of the bond price with increasing government debt levels.

To demonstrate how the option to devalue affects the default decision of the government, Figure 3.3 compares the default region from the benchmark model with the default region from the model without the devaluation option. When the government has the option to devalue the default region is much smaller than without this option as the government prefers to devalue when debt levels are high and productivity is above average (see Figure 3.1).

Although the government defaults less in the benchmark model, the government uses devaluations to lower its debt at relatively low debt levels. Bond prices therefore fall at lower debt levels than in the model without the devaluation option. Figure 3.4 shows the resulting bond price schedule for both models for the same productivity state. In the model without the devaluation option bond prices are higher at low debt levels due to the absence of devaluation risk. However, as can be seen from Figure 3.3 the default region is much larger in the model without the devaluation option. Therefore, at a certain debt level the impact of higher default risk induces bond prices to fall stronger in the model without the option to devalue. In equilibrium

Figure 3.3: Comparison of default regions



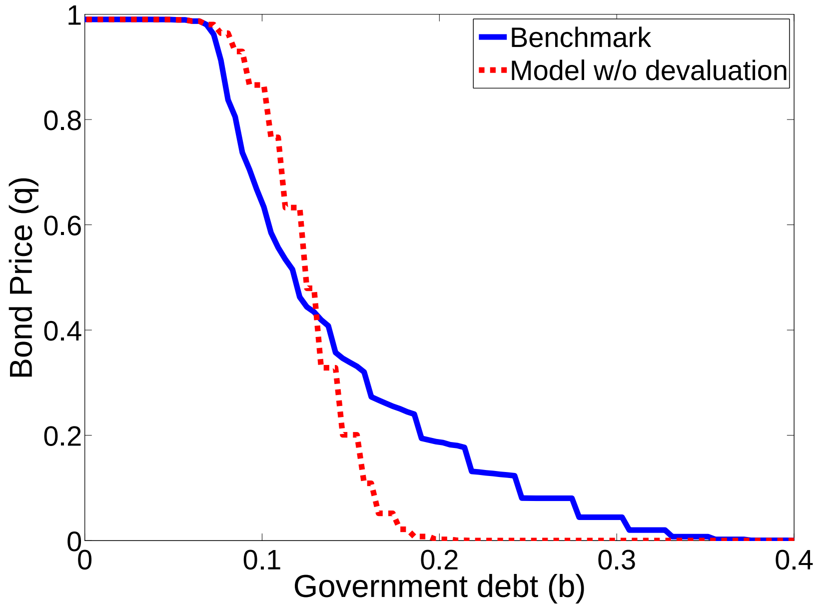
Notes: black area: default regions overlap, grey area: default only when no devaluation possible.

the government chooses lower average debt levels in the benchmark model than in the model without the devaluation option as bond prices fall at lower debt levels. Lower average debt levels lead to a reduction of the default probability of the government. Additionally, the option to devalue provides an alternative to an outright default which also lowers the default probability.

To further illustrate the dynamics of the model, simulations are shown both for the benchmark model and the model without the option to devalue. Figure 3.5 depicts a simulation with a sharp drop in TFP leading to a similar fall in output as the one that occurred in Argentina before the default at the end of 2001. The government optimally decides to devalue in the benchmark model and to default in the model without the devaluation possibility.

In both models government debt increases during the first periods while productivity is high. As the crisis hits, sovereign interest rates increase sharply in the benchmark model and reach an annualized value of close to twenty percent. The government avoids a default in the benchmark model by lowering the debt burden with a devaluation and

Figure 3.4: Comparison of bond price schedules



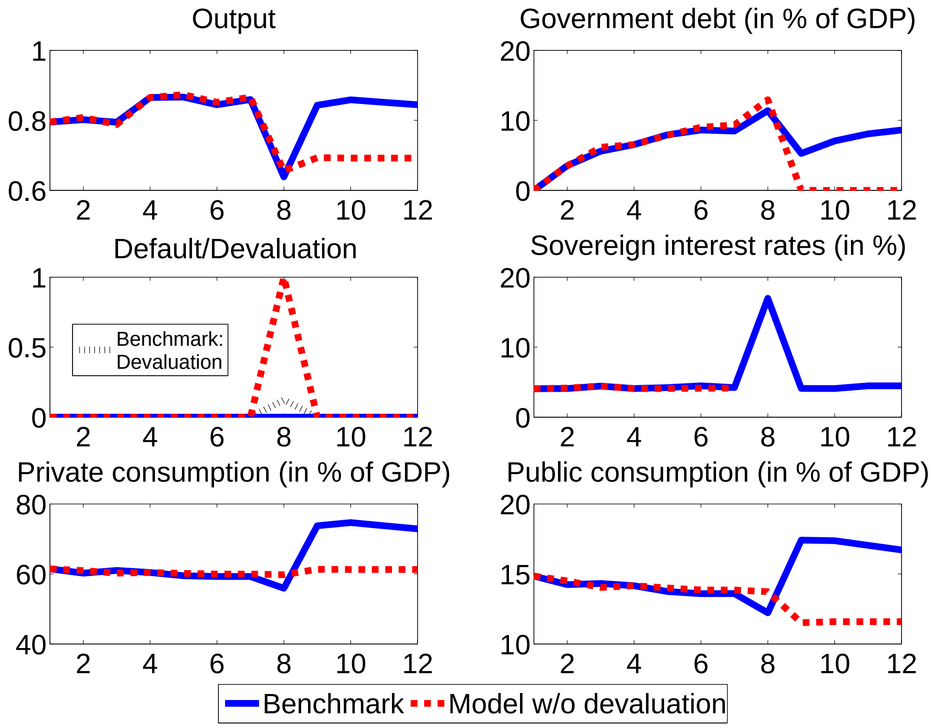
Notes: Continuous blue line denotes the bond price schedule in the benchmark model, dashed red line denotes the bond price schedule in the model without devaluation option. Both bond price schedules are for the same (above average) productivity state.

a simultaneous increase of the labor tax rate.[26] A reduction of both public and private spending helps to avoid a default. In contrast, when the government does not have the option to devalue it optimally decides to default. In this case the default first avoids an increase of labor taxes and a reduction of public and private spending. However, in the periods after the default the exclusion from international financial markets and the output punishment lead to lower public and private consumption than in the benchmark model (in which the default is avoided). This simulation illustrates how the option to devalue might help to avoid a government default. Without a devaluation the necessary increase in taxes and decline in public spending can be prohibitively large and the government prefers to default.

Figure 3.6 depicts a simulation with a less pronounced drop in TFP. In this case the government again decides to devalue in the benchmark model but does *not* default in the model without the option to devalue. As in the first simulation, government

[26] In the period of the devaluation labor taxes increase by two percentage points from 14 to 16 percent.

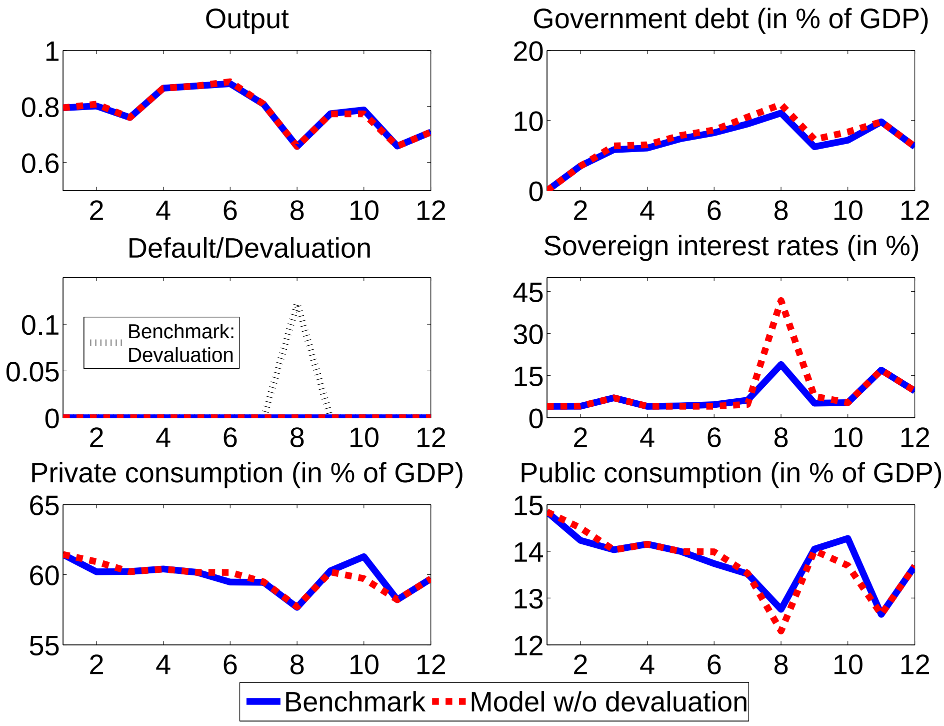
Figure 3.5: Simulation: Devaluation vs. default



Notes: Horizontal axes denote time in quarters. Default=1 denotes a default, while the degree of devaluation is measured in percentage points. For the simulated productivity series there is a devaluation of 12% in the benchmark model and a default in the model without the possibility to devalue. In the model without devaluation the plot for sovereign interest rates stops after the default due to the exclusion from international financial markets.

debt increases in both models during the first periods while productivity is high. The decline in productivity leads to a reduction in output and an increase in sovereign interest rates. In the benchmark model sovereign interest rates peak at around 15 percent and the government decides to devalue. In the model without the devaluation option the government faces higher sovereign interest rates as there is a higher probability of a government default. As the government chooses not to default it has to cut down on public consumption even stronger than in the benchmark model. A devaluation can therefore help to smooth public and private consumption when the government faces adverse shocks.

Figure 3.6: Simulation: Devaluation vs. no default



Notes: Horizontal axes denote time in quarters. Default=1 denotes a default while the degree of devaluation is measured in percentage points. For the simulated productivity series there is a devaluation of 12% in the benchmark model and no default in the model without the possibility to devalue.

3.4.4 Comparison to related studies

The results of the model show that a government that does not have the option to devalue faces a more favorable interest rate schedule at low levels of government debt. This leads to an increase in average debt levels and the probability of default. Arellano and Heathcote (2010) provide a complementary explanation for why a less flexible exchange rate regime can help to increase government debt levels. In their model a dollarization can help to increase the borrowing constraints of the government as it makes the access to international financial markets more valuable. While without dollarization the government can use monetary policy to smooth consumption, the only way to smooth consumption after dollarization is via international financial markets. The government therefore defaults less after dollarization and average debt levels increase.

While Aguiar et al. (2013) do not conduct a quantitative analysis of their model of self-fulfilling debt runs, they obtain results comparable to the ones of this chapter: In their model a strong commitment to low inflation leads to a more favorable interest rate schedule and higher borrowing. In contrast, weak commitment to low inflation leads to high inflation and low equilibrium borrowing. Higher commitment to low inflation corresponds to eliminating the option to devalue in the present model. Eliminating devaluation risk leads to a more favorable interest rate schedule up to a certain debt level, similar to the results of Aguiar et al. (2013). However, in the present model the default region is larger when eliminating the option to devalue which leads to a less favorable interest rate schedule at high debt levels (in difference to the results of Aguiar et al., 2013).

3.5 Conclusion

The results of this chapter show how the option to devalue can reduce the default probability of the government. First, by providing an alternative to an outright default a devaluation can help to avoid defaults during crisis periods with low productivity and high interest rates. Second, the possibility to devalue reduces equilibrium debt levels and thereby reduces default incentives. The option to devalue to lower the debt burden can also make it more attractive for the government to increase taxes and to lower public spending to bridge crisis periods without defaulting. In contrast, without a devaluation the necessary increase in taxes and decline in public spending can be prohibitively large. In this case, a default that avoids these adjustments can become the optimal choice of the government.

The analysis of this chapter also sheds some light on the debate about the 'original sin'. It is difficult for countries to borrow abroad in domestic currency as the resulting devaluation incentives lead to a less favorable interest rate schedule. While a currency board prevents devaluations, the resulting improvement of the interest rate schedule leads to an increase of average debt levels. The higher equilibrium debt levels, however, lead to higher sovereign default risk which causes an increase of average sovereign spreads. This finding is in line with the experience of several southern European countries that adopted the Euro: Around the time that the introduction of the Euro was accounced spreads started to fall, while sovereign spreads increased again during the financial crisis, presumably due to higher default risk.

Appendix to Chapter 3

3.A Government budget constraint

The government budget constraint in nominal terms is

$$P_t g_t = P_t T_t A_t F(l_t) + q_t(b_{t+1}, A_{t+1}) B_{t+1} - B_t, \tag{3.A.1}$$

with B_t denoting the outstanding stock of nominal government bonds. Dividing by the price level P_t gives the government budget constraint in real terms:

$$g_t = T_t A_t F(l_t) + q_t(b_{t+1}, A_{t+1}) b_{t+1} - \frac{b_t}{1 + \pi_t}, \tag{3.A.2}$$

with real government bonds $b_t = \frac{B_t}{P_{t-1}}$ and inflation given by $\pi_t = \frac{P_t}{P_{t-1}} - 1$. The initial P_0 is assumed to be predetermined which, together with the fact that P_t is a function of time, implies that b_t can be treated as a state variable. For better tractability it is assumed that a nominal devaluation leads to an inflation of the same magnitude until the end of the period when government bonds are rolled over. Therefore, in equation (3.2.7) real bonds are divided by the degree of devaluation d_t which equals π_t in equation (3.A.2). This assumption can be rationalized by the fact that small open economies typically have a large amount of imported intermediate goods used for the production of final goods such that a nominal devaluation leads to a strong increase of domestic prices in the following months (see e.g. Borensztein and De Gregorio, 1999). Assuming that domestic inflation increases to a smaller extend than the initial devaluation would decrease the impact of a devaluation on the real value of government debt.

3.B Numerical algorithm

The numerical procedure to solve the model is based on Cuadra et al. (2010). Given the utility and production function one can derive optimal labor supply and optimal levels of consumption of domestic and foreign tradables from the first order conditions of the households and the households' budget constraint. Optimal labor supply and optimal consumption decisions can be expressed as a function of the tax rate and the terms of trade that result from the devaluation decision:

$$l^* = \left[A(1-T) \frac{1}{\chi} \phi^{\phi} \left(\tau (1-\phi) \right)^{(1-\phi)} \right]^{\frac{1}{\psi}} \tag{3.B.1}$$

$$c_H^* = \phi A(1-T) l^* \tag{3.B.2}$$

$$c_F^* = (1-\phi) A(1-T) l^* \tau \tag{3.B.3}$$

The expression in (3.B.1) can be inserted in (3.2.7):

$$g = TA\, l^* + q(b', A')b' - \frac{b}{1+d}, \tag{3.B.4}$$

Starting with an initial guess for the bond price function $(q)_0$ as well as for the value functions $(V^o)_0$, $(V^c)_0$ and $(V^{def})_0$ the following algorithm is used:

1. For every state combination (A, b, b', d) determine the tax rate $(T)_0$ that maximizes the utility function (3.3.1)

2. Determine $(V^o)_1$, $(V^c)_1$, $(V^{def})_1$ and the default decision given $(q)_0$ and $(T)_0$.

3. Update the price schedule $(q)_1$ and the value functions $(V^o)_1$, $(V^c)_1$ and $(V^{def})_1$.

4. Repeat iterating until the value functions and the bond price function converge.

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