Sovereign and Private Default Risks over the Business Cycle*

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Abstract

Sovereign debt crises are often accompanied by deep recessions with sharp declines in external credit to the private sector. In a sample of emerging economies we find that both, sovereign and private risk premia are countercyclical. This paper presents a model of a small open economy that accounts for these empirical regularities. It includes private firms which finance a fraction of imports by external debt and are subject to idiosyncratic and aggregate productivity risk, and a government which borrows internationally and taxes firms to finance public expenditures. The model gives rise to endogenous private and sovereign credit spreads and a dynamic feedback mechanism between sovereign and private default risks through the endogenous response of fiscal policy to adverse productivity shocks.

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1 Introduction

Sovereign default is a recurrent phenomena in emerging economies. Default episodes are typically associated with severe recessions, characterized by sharp drops in output, investment and imports. Recent empirical studies further suggest that sovereign default is followed by worsening conditions for external finance for the private sector. Arteta and Hale (2008) show that foreign credit to non-financial firms contracts sharply in the aftermath of sovereign debt crises.[1] Ağca and Celasun (2012) find that higher external sovereign debt in emerging markets translates into higher borrowing costs for the private sector, and much more so in countries that have experienced sovereign default episodes in the past. What is the explanation for these links between sovereign debt and the private sector's access to foreign credit? And how do these relations affect macroeconomic conditions around default episodes?

To address these questions, we investigate the dynamic interrelations between sovereign and private credit risks in emerging economies and their effects on macroeconomic outcomes. We first document several business-cycle facts about risk premia on sovereign and private external debt for a sample of emerging and developed economies, and we consider the behavior of these risk premia during Argentina's sovereign debt crisis in 2002. In line with earlier literature, the default crisis was accompanied by a strong decline in imports and by an increase of sovereign and private risk premia. But while the sovereign premium rose persistently, the increase of the private premium was more transitory. Over the business cycle, private and sovereign premia are countercyclical, which is a robust phenomenon that is independent of the inclusion of default episodes.

We then build a dynamic, stochastic model of a small open economy to account for these observations. Our modeling approach follows the recent literature on sovereign debt in incomplete markets economies with an endogenous default choice of the government, e.g. Aguiar and Gopinath (2006) and Arellano (2008). The model has domestic households, domestic firms producing final goods and intermediate goods, a domestic government and foreign lenders. Final goods firms produce the output with imperfectly substitutable domestic and foreign intermediate goods. A fraction of imported intermediate goods must be financed by external credit. Since firms face idiosyncratic and aggregate productivity shocks, their credit is subject to default risk, so that risk-neutral international investors charge a risk premium on private debt. Households value private consumption, leisure and a public good provided

[1] See also Das et al. (2010) who obtain similar results for a broader data set.

by the government. The government acts in the interest of domestic households, it levies a linear sales tax and borrows internationally so as to smoothen the provision of the public good and to balance fluctuations in tax revenues over the business cycle. In any period, the government has the option to default on the outstanding debt, which gives rise to an endogenous risk premium on sovereign debt. In the event of default, the government is temporarily excluded from international financial markets in which case it must finance public expenditures solely from taxes.

In a quantitative application to Argentina we show that our theoretical framework mimics the empirical facts of a typical emerging market economy, in particular countercyclical sovereign and private spreads, volatile imports and deep recessions in default. Moreover, taxes are countercyclical and government spending is procyclical, in line with the empirical evidence of procyclical fiscal policy in emerging market economies (e.g. Talvi and Vegh (2005), Ilzetzki and Vegh (2008)).

Similar to Cuadra et al. (2010), the procyclicality of fiscal policy is a direct consequence of countercyclical sovereign default risk. If the economy enters a recession, external public debt becomes more expensive due to the higher default risk, and this induces the government to raise tax rates so as to finance public expenditures. This procyclicality of fiscal policy is important for macroeconomic amplification in our model: Higher tax rates in recessions depress firms' profitability even further and induce more firms to default on their external debt. In turn, higher private spreads reduce import demand which deepens the recession and amplifies sovereign default risk. In case of a default, by not repaying debt the government is able to reduce tax rates which stimulates profitability and reduces the private risk premium. Consequently, in line with the data, the increase of the private premium around a sovereign default event is rather short-lived.

To explore the dynamic feedback mechanism between tax policy and sovereign and private credit risks, we perform two experiments. First, we shut down the endogenous tax response. Our simulation results show that with an exogenous tax policy the feedback mechanism between sovereign and private default risks becomes significantly weaker. The recession is less severe, but the recovery after the default is substantially slower than with an endogenous tax rate. Second, we abstract from endogenous private credit risk. With an exogenous private interest rate, imports are less volatile and the drops in output and imports during a default event are reduced.

Closely related to our framework, Mendoza and Yue (2012) consider a model in which firms produce final output from domestically produced and imported inter-

mediate goods. A share of the imported intermediate goods is financed by external debt.[2] Different from ours, however, they assume that firms are always able to borrow at the risk-free rate, which is at odds with the evidence.[3] Furthermore, all firms and the government are simultaneously excluded from international financial markets if the government chooses to default. This in turn causes firms to substitute away from imports towards domestically produced goods, generating output costs that are required to account for countercyclical sovereign spreads. Our model also has a contraction in imports and therefore an endogenous output cost of sovereign default, but this factual reaction does not require to shut all firms out of financial markets together with the defaulting government. Moreover, our model has a direct impact of sovereign spreads on private spreads via the endogenous reaction of fiscal policy.

Similar to our paper, Arellano et al. (2017) explore the consequences of the joint dynamics of sovereign and private default risk for real economic activity, but in contrast to our paper they assume a reduced-form relationship between sovereign and private default risk and apply their model to Italy. In a related contribution, de Ferra (2016) develops a two-sector framework with a labor income tax to study the dynamic interaction between fiscal policy and corporate credit risk for the case of Italy.

We are abstracting from the role of domestically held debt, often on the balance sheet of banks, that is also discussed as a potential source of amplification. For instance, in theoretical contributions based on finite–horizon economies, Brutti (2011) and Gennaioli et al. (2014) argue that sovereign default harms the balance sheets of domestic banks or private investors, which triggers contractions in credit and investment. Engler and Große-Steffen (2016), Niemann and Pichler (2016), and

[2]The broader literature on sovereign debt in quantitative macroeconomic models considers political uncertainty (e.g. Cuadra and Sapriza (2008) and Scholl (2017)), debt renegotiations (e.g. Yue (2010)), the maturity structure of debt (e.g. Hatchondo and Martinez (2009), Arellano and Ramanarayanan (2012) and Chatterjee and Eyigungor (2012)), or bailouts (e.g. Roch and Uhlig (2016), Fink and Scholl (2016), Kirsch and Rühmkorf (2015)). In all these papers, there is no credit to the private sector.

[3]In an earlier working paper version (NBER Working Paper No. 17151), Mendoza and Yue (2012) assume that private firms borrow at the same rate as the government and default simultaneously which is also counterfactual. Pancrazi et al. (2015) consider a dynamic general equilibrium model with sovereign default and private credit granted by domestic banks that borrow internationally. As Mendoza and Yue (NBER Working Paper), they assume that banks borrow at the same rate as the government from international creditors.

Sosa-Padilla (2012) build quantitative stochastic general equilibrium models with a similar feature. While this channel is presumably important in countries where a large share of government debt is held domestically, it may be less relevant for most emerging markets. Further, Arteta and Hale (2008) show that the decline in external credit during sovereign debt crises is concentrated in the non-financial sector, which motivates why we abstract from financial intermediaries in our model.

Besides the banking channel, other contributions also consider spill-over effects of sovereign default on external credit of firms. Andreasen (2015) suggests a signaling mechanism, based on the idea that the government's repayment decision provides new information regarding the institutional quality (such as recovery rates) which affects the financial conditions of private firms. Sandleris (2014) argues that sovereign default can trigger a collapse of private credit even when no debt is held domestically. In his model, a sovereign default reduces the firms' collateral value, which limits their borrowing capacity. Arellano and Kocherlakota (2014) propose a reverse mechanism: due to informational frictions in private credit markets, private default crises can emerge as a coordination equilibrium which possibly triggers a sovereign debt crisis.

The remainder of this paper is organized as follows. In the next section, we document empirical evidence about sovereign and private credit risk in emerging market and developed economies. In Section 3, we describe the model framework, define the recursive equilibrium and explain the main determinants of sovereign and private default risks. In Section 4 we calibrate the model to the Argentine economy in order to illustrate the quantitative significance of the interplay between sovereign and private credit risks that our model generates. Section 5 concludes.

2 Empirical Facts

2.1 Cyclical Properties

We document empirical regularities of private and sovereign default risks considering emerging market economies as well as developed economies. Our sample of emerging market economies consists of Argentina, Brazil, Chile, Ecuador, Korea, Malaysia, Mexico, Peru, Philippines, Russia and Venezuela, while our sample of developed small open economies includes Australia, Canada, Netherlands, New Zealand, Sweden and Switzerland.[4] Our sample covers the period from the early 1970s (early 1990s) until

[4] The choice of countries is based on the sample analyzed by Neumeyer and Perri (2005), but we add emerging market economies for which we have at least ten years of data. Moreover, we add

	$\mathrm{E}(s)$	$\mathrm{E}(s^p)$	$\sigma(s)$	$\sigma(s^p)$	$\rho(s, s^p)$	$\rho(s, y)$	$\rho(s^p, y)$
Argentina	5.97	8.45	2.75	4.81	0.87***	-0.85***	-0.81***
Brazil	4.80	39.72	3.49	9.39	0.54***	-0.59***	-0.21**
Chile	1.47	1.96	0.55	0.88	0.63***	-0.40***	-0.34***
Ecuador	9.37	7.52	3.69	1.84	0.69***	-0.34**	-0.18
Korea	1.94	1.11	1.61	0.87	0.55***	-0.75***	-0.65***
Malaysia	1.92	3.10	1.47	0.75	0.38***	-0.47***	0.06
Mexico	2.50	6.66	1.03	4.63	0.71***	-0.49***	-0.19
Peru	3.58	7.68	1.97	1.69	0.46***	-0.75***	-0.11
Philippines	3.43	4.10	1.44	1.07	-0.11	-0.75***	-0.02
Russia	3.53	6.97	2.69	2.96	0.81***	-0.53***	-0.25**
Venezuela	7.36	8.03	1.48	2.74	0.33	-0.53***	-0.21
Australia	1.92	2.63	1.50	1.78	-0.30***	-0.26***	0.20**
Canada	0.88	3.36	0.76	0.59	0.13	-0.24***	0.57***
Netherlands	-0.23	2.65	0.82	3.20	0.16	-0.09	-0.11
New Zealand	2.51	1.74	1.12	0.64	-0.16	-0.16	-0.40***
Sweden	0.75	4.27	1.54	1.24	0.81***	-0.73***	-0.91***
Switzerland	-2.88	1.91	2.17	1.50	0.34***	0.24***	-0.64***
Emerging Markets	4.17	8.66	2.02	2.88	0.53	-0.59	-0.26
Developed Economies	0.49	2.76	1.32	1.49	0.16	-0.21	-0.22

Table 1: Sovereign and Private Interest Spreads over the Business Cycle

Notes: s denotes the annualized sovereign interest spread while s^p refers to the annualized private interest spread. y denotes real GDP. Risk premia are demeaned and GDP is log-linearly detrended before business-cycle statistics are calculated. Argentina, Ecuador, Russia and Venezuela had default episodes during the time period that we consider. To calculate business-cycle statistics we exclude the default events and consider the following restricted samples: Argentina 1994Q1-2001Q4, Ecuador 2000Q4-2008Q3, Russia 2000Q4-2012Q3, Venezuela 1999Q1 - 2004Q4. Significance is denoted by stars ('*' 10%, '**' 5%, '***' 1%).

the second quarter of 2013 for the developed (emerging markets) economies. Due to data availability the sample periods for the individual countries differ in their starting and end dates. More details on calculations, data sources and further statistics can be found in Appendix B and Appendix C.

We follow Arellano and Kocherlakota (2014) and calculate private risk premia as the spread between the dollar domestic lending rate and the interest rate on a US bond with similar maturity. If foreign currency lending rates are not available, we use the spread between the local currency domestic lending rate and the local currency domestic deposit rate.[5] Sovereign risk premia are obtained from the Emerging Market Bond Index (EMBI). We use the risk premium calculated by JP Morgan instead of the difference between the EMBI yield to maturity and a US bond, because JP Morgan's risk premium is adjusted for different payment streams.[6]

In Table 1 we summarize the business-cycle properties of sovereign and private interest spreads for our samples of emerging market and developed small open economies, excluding default events in order to provide meaningful comparisons. The business-cycle statistics reveal several empirical regularities. First, the sovereign risk premium tends to be lower and less volatile than its private counterpart, both in emerging markets and developed economies. This result is in line with the hypothesis that the sovereign rating provides a ceiling to private company ratings.[7] Second, private and public risk premia in emerging market economies are higher than in developed economies. Third, the sovereign interest spread is strongly countercyclical in emerging markets while the cyclical behavior is less pronounced in developed economies. Private interest rate spreads tend to be countercyclical, too, but to a lesser extent compared to the sovereign spreads.[8]

2.2 Dynamics Around Default

While our analysis of the cyclical properties of sovereign and private risk premia explicitly abstracts from default events, we now focus on the dynamics of key macroe-

Switzerland to the sample of developed economies.

[5]For details see Table 6 in Appendix C.

[6]The difference between EMBI spreads and the difference between the EMBI yield to maturity and a five-year US bond is negligible.

[7]See also Borensztein et al. (2013) who provide further evidence on the sovereign ceiling.

[8]Our results are in line with the evidence in Bai and Wei (2012), Bedendo and Colla (2015) and Klein and Stellner (2014). They show that corporate and sovereign CDS spreads in Europe comove closely.

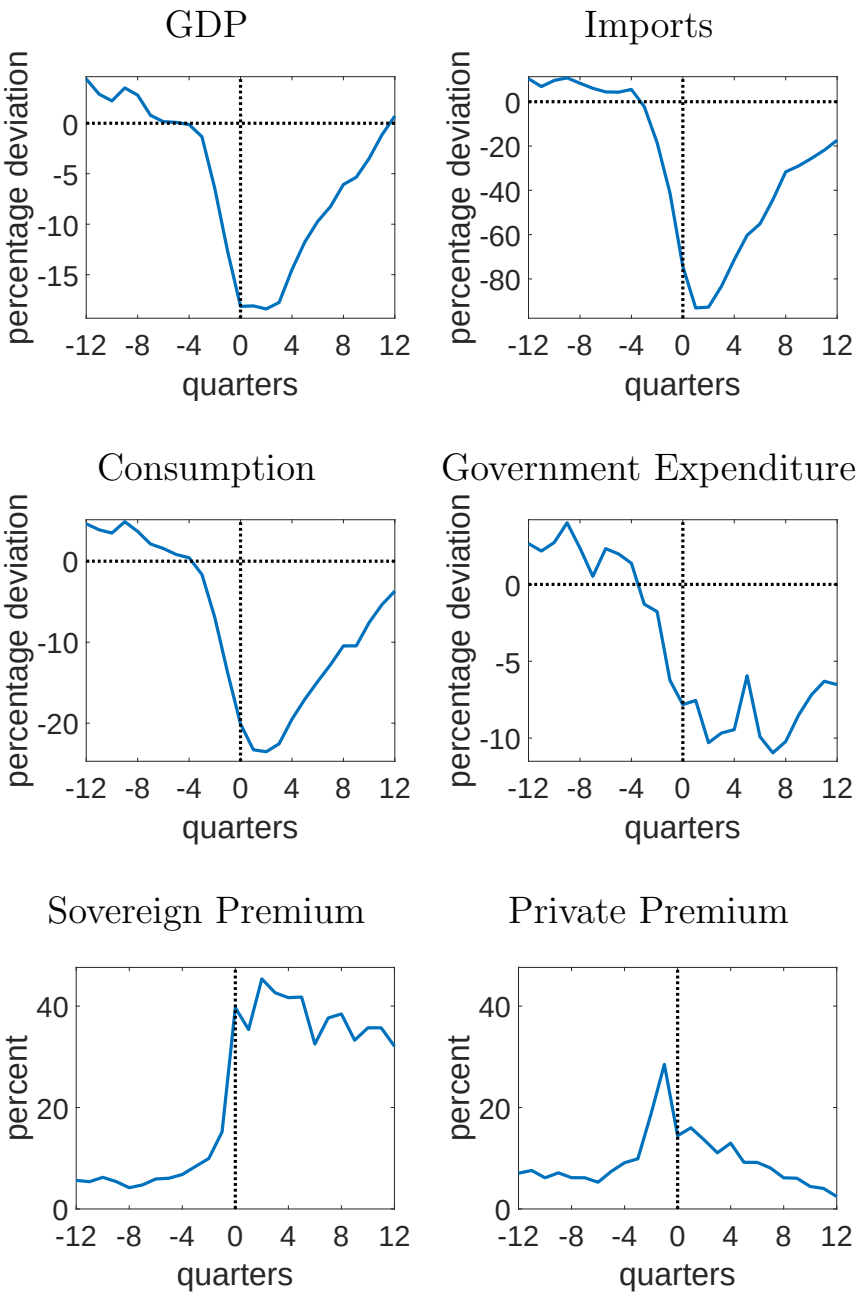

Figure 1: Default Dynamics

Notes: The figure shows the dynamic patterns of GDP, imports, consumption, government expenditures, the annualized sovereign premium and the annualized private premium 12 quarters before and after Argentina's default in 2002. GDP, imports, consumption and government expenditures are log-linearly detrended, using data until the default quarter. The sovereign premium is the EMBI Global spread, and the private premium is calculated as the difference between short-term bank credit interest rate in US$ and the 3-month US T-Bill.

conomic variables during the sovereign default episode of Argentina (2002Q1). We consider GDP, imports, and the sovereign and private interest spread.[9] In Figure 1 we plot the patterns of the variables twelve quarters before and after the default event in quarter $t = 0$. GDP and imports are shown as percentage deviations from a linear trend while the premia are depicted in percent.

First, we observe a deep recession with a substantial drop in imports around the default event. Relatedly, Gopinath and Neiman (2014) show that the recession in the course of Argentina's default was accompanied by a substitution of imported intermediate goods by domestic intermediate goods. The recession translates into a deep fall in consumption and government expenditures, reflecting a procyclical government spending policy. The decline in consumption is more pronounced but less persistent than the decline in government expenditures. Furthermore, we observe a strong and persistent increase of the sovereign risk premium during the default episode. Private credit costs increase as well, but the rise in the private spread is less pronounced and more transitory.[10] These findings are in line with Ağca and Celasun (2012) who show that private credit costs increase during sovereign debt crises.

During the recession prior to the sovereign default in January 2002, the Argentine government implemented a series of austerity measures. Sturzenegger and Zettelmeyer (2006) document several rounds of tax increases and spending cuts to reduce the deficit prior to the default. Cuadra et al. (2010) discuss several episodes in which the Argentine government implemented a countercyclical tax policy. For example, tax rates were significantly reduced during the economic boom in 1991-1994 and increased at the beginning of the recession in 1995. When economic growth resumed in 1996, the government lowered tax rates.

[9]Ultimately, for the quantitative evaluation of our model, we are interested in imports of intermediate goods, but since data on them is available only on an annual basis, we use overall imports as a proxy. Following Mendoza and Yue (2012) in the definition of intermediate goods, we calculate the share of intermediate goods in imports. On average these imports account for around 58% of total imports in emerging markets and around 48% in developed economies.

[10]The private spread is measured as the difference between the average of interest rates at which a selected group of banks is willing to lend to the most creditworthy customers on 30-day loans denominated in US$ and the three month U.S. T-Bill rate. Since the lending rate considers only the most creditworthy customers, sample selection should not play an important role for the fall in the private spread after the default.

3 A Model of Sovereign and Private Default Risk

We describe a stochastic dynamic general equilibrium model of a small open economy. The economy is hit by aggregate productivity shocks and has many firms who are subject to idiosyncratic productivity shocks. These firms borrow internationally and decide to default if productivity is sufficiently low, which generates an endogenous premium on private external debt. The government borrows abroad to smoothen the provision of a public good, and it also has the option to voluntarily default on its debt, which gives rise to a risk premium on public debt.

Our small open economy comprises four types of agents: a representative household, final goods firms, intermediate goods firms and the domestic government. Foreign investors lend to the government and to private firms.

The domestic household owns firms and supplies labor. All firms are perfectly competitive. Final goods firms produce output from two differentiated intermediate goods. One of them is an import good, the other is produced domestically by intermediate goods firms employing labor. A fraction of imported intermediate goods is financed by external private debt. As it is standard in the quantitative macroeconomic literature the working-capital loan is intraperiod[11] and, similar to Arellano et al. (2016), final goods firms make their import and borrowing decision before they are hit by idiosyncratic productivity shocks. Instead of redeeming their debt, firms can opt to default if the continuation profit is negative.

The representative household enjoys utility from consumption, leisure and from a public good. The government provides the public good, taxes sales[12] and finances deficits by issuing external debt. Following Arellano (2008), if the government chooses to default, it is excluded from international borrowing for a stochastic number of periods. In addition, during exclusion, the country suffers an output loss which is exogenous to the model. Even when the government is excluded from international borrowing, private firms retain access to external credit.[13]

[11] Compare for example Neumeyer and Perri (2005), Jermann and Quadrini (2012) and Mendoza and Yue (2012).

[12] For simplicity, a sales tax is the only tax instrument of the government. Other distortionary taxes should have similar implications, as long as they reduce the profitability of firms.

[13] Therefore, any spillover from sovereign default on the private credit market is not assumed exogenously but is the outcome of an endogenous equilibrium response. We also do not allow the government to impose capital controls to restrain the borrowing of domestic firms. Whether or not the government would want to make use of such policy tools would be an interesting question for future research.

The timing within each period is as follows. First, aggregate productivity is realized, the government decides whether to default on its external debt and it adjusts current policies, i.e. the sales tax, expenditures for the public good and debt issuance. Final goods firms make import decisions and borrow abroad. Intermediate goods firms hire workers and produce. Second, final goods firms are hit by idiosyncratic productivity shocks and decide whether to default or to repay their outstanding debt obligations. Active (non-defaulting) firms buy domestic intermediate goods and produce output.

3.1 Households

The representative household has preferences

$$\mathrm{E}_0 \sum_{t \geq 0} \beta^t u(c_t - v(\ell_t), g_t) \ ,$$

where c_t and g_t are consumption of the private and the public good, and ℓ_t is labor supply. $0 < \beta < 1$ denotes the discount factor, u is strictly increasing and concave and v is strictly increasing and convex. The household does not borrow or lend internationally and thus consumes all labor and profit income. Therefore the household's budget constraint is $c_t = \Pi_t + w_t \ell_t$, where Π_t are aggregate profits and w_t is the real wage. As implied by this notation, the gross price of the consumption good is normalized to unity.

3.2 Firms

Intermediate goods firms produce the domestic intermediate good from labor with linear technology $m_t = \ell_t$. Since firms operate under perfect competition, the price of the domestic intermediate good equals the real wage w_t.

Let $s_t \in \{N, D\}$ denote whether the country is in a normal state (N) or in a sovereign default episode (D). Final goods firms produce output from domestic and foreign intermediate goods, m_t and m_t^* with technology $x_t z_t f(m_t, m_t^*)$ for $s_t = N$. x_t and z_t are idiosyncratic and aggregate productivity, respectively, and f has constant returns to scale and is concave. While z_t follows a Markov process and is known at the beginning of the period, idiosyncratic productivity is realized after firms make import decisions and borrow but before they buy domestic intermediate goods. Then x_t is drawn i.i.d. from cumulative distribution function $X(.)$. With τ_t denoting the sales tax, we write the firm's net revenue as $x_t \tilde{z}_t f(m_t, m_t^*)$ with $\tilde{z}_t \equiv (1 - \tau_t) z_t$. If the

country is in a sovereign default episode, $s_t = D$, the country faces exogenous output costs such that output is $x_t h(z_t) f(m_t, m_t^*) \leq x_t z_t f(m_t, m_t^*)$ with function $h(.) \leq 1$, and net revenue is $x_t \tilde{z}_t f(m_t, m_t^*)$ with $\tilde{z}_t \equiv (1 - \tau_t) h(z_t)$.

Imported intermediate goods are bought at the world price p^*. We assume that firms must finance the fraction ξ of imports by external debt and the remaining fraction by domestic funds. International credit markets are incomplete, so that external private debt has gross interest rate R_t which is unconditional on idiosyncratic productivity realizations and which reflects the firms' default risk. If a firm imports m_t^*, its external debt is $R_t \xi p^* m_t^*$. After idiosyncratic productivity x_t is realized, the firm has two options.

Either the firm stays in business and repays the international debt. Such a firm optimally buys domestic intermediate goods proportional to imports, $m_t = \Phi(\frac{x_t \tilde{z}_t}{w_t}) m_t^*$, where Φ is an increasing function whose functional form depends on the production function f. Its profit before interest payments is also linear in m_t^*, namely $\pi(x_t \tilde{z}_t, w_t) m_t^*$, where π is increasing (decreasing) in the first (second) argument. Hence the shareholders' profit is $\pi(x_t \tilde{z}_t, w_t) m_t^* - R_t \xi p^* m_t^* - (1 - \xi) p^* m_t^*$.

Alternatively, the firm may opt to default in which case the firm does not buy any domestic intermediate goods and shareholders lose the sunk expenses for the imported goods which are $(1 - \xi) p^* m_t^*$.

Therefore, the firm defaults whenever the continuation profit from default, which is $-(1-\xi) p^* m_t^*$, is larger than the continuation value from repayment, $\pi(x_t \tilde{z}_t, w_t) m_t^* - R_t \xi p^* m_t^* - (1 - \xi) p^* m_t^*$. This is the case when $x < \overline{x}_t$ where the default threshold is defined by

$$\pi(\overline{x}_t \tilde{z}_t, w_t) = R_t \xi p^* \ . \tag{1}$$

Evidently, $\overline{x}_t$ decreases in $\tilde{z}_t$ and increases in (w_t, R_t, p^*), but it is independent of the amount of imports. In general equilibrium, however, there is an indirect effect of the import volume on default risk via domestic intermediate goods and labor markets.

At the beginning of the period, final goods firms choose imports m_t^* to maximize the expected profit value

$$\int_{\overline{x}_t}^{\infty} [\pi(x \tilde{z}_t, w_t) - R_t \xi p^*] m_t^* \ dX(x) - (1 - \xi) p^* m_t^* \ .$$

Because this objective is linear in m_t^*, the first-order condition implies zero expected profits,[14]

$$(1 - \xi) p^* = \int_{\overline{x}_t}^{\infty} [\pi(x \tilde{z}_t, w_t) - R_t \xi p^*] \ dX(x) \ . \tag{2}$$

[14]The firm's shareholders incur a loss either when the firm defaults or when the profit of a

While some firms default, new firms may enter the economy in any period. Due to the constant-returns specification, the number of firms is irrelevant. Without loss of generality, we set the mass of firms to one and interpret m_t^* as either aggregate or firm-level imports. Because firms are ex-ante homogeneous, they are all affected by sovereign default events in the same way. Introducing richer firm heterogeneity may be helpful to address additional interesting questions but is beyond the scope of this paper.

3.3 International Investors

Risk-neutral international investors have access to an international bond market with constant gross interest rate $\overline{R}$. They lend to domestic firms if the expected gross return of credit equates the safe return. We assume that in the event of a private default, lenders are able to recover a fraction η of the value of credit-financed import goods, where parameter η reflects the institutional features of the country, such as the quality of legal enforcement.

The investors' arbitrage condition therefore states that

$$\overline{R} = R_t\Big[1 - X(\overline{x}_t)\Big] + \eta X(\overline{x}_t) \ , \tag{3}$$

where $X(\overline{x}_t)$ is the default probability of final goods firms.

3.4 Private Sector Equilibrium

Note that labor supply is $(v')^{-1}(w_t)$ and that labor demand for any firm with idiosyncratic productivity $x \geq \overline{x}_t$ is equal to this firm's demand for domestic intermediate goods which is $\Phi(\frac{x\tilde{z}_t}{w_t})m_t^* = m_t$. Therefore, the labor market clears in period t if

$$\int_{\overline{x}_t}^{\infty} \Phi\Big(\frac{x\tilde{z}_t}{w_t}\Big)m_t^* \ dX(x) = (v')^{-1}(w_t) = \ell_t \ . \tag{4}$$

Households consume all their income, and since aggregate profit income is zero,

$$c_t = w_t\ell_t \ . \tag{5}$$

Given current aggregate productivity z_t, the sales tax τ_t, and the default state s_t, the private-sector equilibrium $(w_t, \overline{x}_t, \ell_t, R_t, m_t^*, c_t)$ solves the six equations[15] (1)–(5).

continuing firm is negative which happens when $[\pi(x\tilde{z}_t, w_t) - R_t\xi p^*]m_t^* - (1-\xi)p^*m_t^* < 0$. Otherwise (if x is sufficiently large), profits are positive.

[15] Equation (1) presupposes default in equilibrium. There can also be a boundary solution where $\overline{x}$ is at the infimum of the support of $X(.)$ and (1) holds with inequality.

We write $c_t = \mathcal{C}(z_t, \tau_t, s_t)$ and $\ell_t = \mathcal{L}(z_t, \tau_t, s_t)$ for equilibrium consumption and employment, and we assume that a solution of the private-sector equilibrium exists for the range of admissible values for (z_t, τ_t, s_t).[16] We further write aggregate output as $y_t = \mathcal{Y}(z_t, \tau_t, s_t)$, which is

$$y_t = \int_{\overline{x}_t}^{\infty} [z_t + \mathbb{I}_{s_t=D}(h(z_t) - z_t)] x f\Big(\Phi\Big(\frac{x\tilde{z}_t}{w_t}\Big), 1\Big) m_t^* \, dX(x) \ , \tag{6}$$

and we denote the private sector interest rate by $R_t = \mathcal{R}(z_t, \tau_t, s_t)$.

Because of our assumption that private credit is repaid at the end of the period, the private sector equilibrium does not depend on any endogenous state variables, such as the firms' net worth, which greatly simplifies the model. Including such state variables would complicate the solution of the model considerably, as it would involve intertemporal decisions of firms that have to forecast future tax policies of the government.

3.5 The Government

The government maximizes expected utility of the representative household without commitment over future policy choices. At the beginning of period t, it decides whether to default on its external debt obligation. If it does so, it is excluded from international borrowing in the default period. In any future period, it regains access to international credit with exogenous probability θ. In a period of market exclusion, the government finances expenditures for the public good by the sales tax revenues, $g_t = \tau_t y_t$. If the government can borrow internationally, it issues new debt $b_{t+1} < 0$ at price $q(z_t, b_{t+1})$, facing the flow budget constraint $g_t = \tau_t y_t + b_t - q(z_t, b_{t+1}) b_{t+1}$. The price of debt reflects the default-risk adjusted rate of return of foreign lenders. The government takes the private sector's responses as given.

The relevant state variables for the government at the beginning of any period are (z, b, s), with $s \in \{N, D\}$. The government's value function in any period with access to international financial markets is

$$V(z, b, N) = \max \Big\{ V^N(z, b), V^D(z) \Big\} \ , \tag{7}$$

[16] We also make sure that the equilibrium interest rate is the stable solution of equation (3); namely, deviations to a lower rate may not raise investors' expected return. This requirement is meaningful because (3) typically has two solutions, the larger of which is unstable. For the parameterization that we use in the next section, we confirm that there is a unique stable solution.

where V^N (V^D) are continuation utilities after no default (default). If the government stays solvent, the recursive formulation of its problem is

$$V^N(z,b) = \max_{g,\tau,b_+} u(c - v(\ell), g) + \beta \mathrm{E}_z V(z_+, b_+, N) \ , \tag{8}$$

subject to

$$g = \tau y + b - q(z,b_+)b_+ \ ,$$
$$c = \mathcal{C}(z,\tau,N), \ \ell = \mathcal{L}(z,\tau,N), \ y = \mathcal{Y}(z,\tau,N) \ .$$

The first condition is the budget constraint of the government. The other three equations express the private-sector equilibrium in reduced form, as derived in the previous subsection.

If the government has defaulted in some period and is excluded from international bond markets, the recursive problem is

$$V^D(z) = \max_{g,\tau} u(c - v(\ell), g) + \beta \mathrm{E}_z \Big[\theta V(z_+, 0, N) + (1-\theta) V^D(z_+)\Big] \ , \tag{9}$$

subject to $g = \tau y$ and

$$c = \mathcal{C}(z,\tau,D), \ \ell = \mathcal{L}(z,\tau,D), \ y = \mathcal{Y}(z,\tau,D) \ .$$

The set of default states is

$$\Sigma^D = \Big\{(z,b) \mid V^D(z) > V^N(z,b)\Big\} \ . \tag{10}$$

The government's default probability is

$$\lambda(z,b_+) \equiv \mathrm{Prob}\Big((z_+,b_+) \in \Sigma^D \ \Big| z\Big) \ .$$

International investors lend to the government if

$$q(z,b_+) = \frac{1 - \lambda(z,b_+)}{\overline{R}} \ . \tag{11}$$

The bond price function reflects the endogenous sovereign default risk.[17]

[17]While the government borrows at the end of period $t-1$ to repay debt in period t, domestic firms borrow within period t. For foreign investors, this difference is irrelevant as long as both loans have the same maturity (i.e., one model period). Furthermore, as in any model set in discrete time, the difference in timing of the intraperiod versus interperiod loans can be made arbitrarily small.

3.6 Equilibrium Definition

Definition: *A recursive equilibrium is given by*

(i) *value functions* $V(z,b,s)$, $V^D(z)$, $V^N(z,b)$ *and policy functions* $b_+ = \mathcal{B}(z,b,s)$, $\tau = \mathcal{T}(z,b,s)$, $g = \mathcal{G}(z,b,s)$ *of the government, solving problems (7)–(9), and a default set* Σ^D *satisfying (10).*

(ii) *a pricing function* $q(z,b_+)$ *satisfying the arbitrage condition of foreign lenders (11).*

(iii) *a private sector equilibrium, defining consumption* $c = \mathcal{C}(z,\tau,s)$, *employment* $\ell = \mathcal{L}(z,\tau,s)$, *output* $y = \mathcal{Y}(z,\tau,s)$, *and the private interest rate* $R = \mathcal{R}(z,\tau,s)$ *for* $s = N, D$, *satisfying (1)–(6).*

A solution to a recursive equilibrium specifies optimal plans for the government and for all private agents in this economy. It includes situations with and without sovereign default. The bond pricing function and the private sector interest rate reflect the risk premia associated with optimal default choices of the government and of the private sector.

4 Quantitative Analysis

In this section, we solve the model numerically to study its quantitative properties. We apply the model to Argentina which is often used as the benchmark for studies on sovereign default given its default history and data availability. We calibrate the model at quarterly frequency and choose parameters to match several empirical targets.

4.1 Calibration

4.1.1 Functional Forms

We choose a CES production function of final goods:

$$f(m,m^*) = \left[(1-\omega)(m)^\rho + \omega(m^*)^\rho\right]^{1/\rho},$$

with $\rho < 1$ and $\omega \in (0,1)$. This implies that the demand for domestic input per unit of foreign input is

$$\Phi(q) = \omega^{1/\rho}\Big[(q(1-\omega))^{\frac{\rho}{\rho-1}} - 1 + \omega\Big]^{-1/\rho} \ , \ q = \frac{x\tilde{z}}{w} \ .$$

Profits (before interest) per unit of imports are

$$\pi(x\tilde{z}, w) = w\Big(\frac{\omega}{1-\omega}\Big)^{1/\rho}\Big[\Big(\frac{x\tilde{z}}{w}\Big)^{\frac{\rho}{\rho-1}}(1-\omega)^{\frac{1}{\rho-1}} - 1\Big]^{\frac{\rho-1}{\rho}} \ .$$

Both Φ and π are defined for $q = x\tilde{z}/w < (1-\omega)^{-1/\rho}$ if $\rho > 0$ and for $q = x\tilde{z}/w > (1-\omega)^{-1/\rho}$ if $\rho < 0$.

Idiosyncratic productivity is uniformly distributed in the interval $[1-\zeta, 1+\zeta]$, so that $X(x) = \frac{x-1+\zeta}{2\zeta}$.

We employ the GHH preferences (Greenwood et al. (1988)):

$$u(c,\ell,g) = \frac{\Big(c - \frac{\psi}{1+\psi}\ell^{\frac{1+\psi}{\psi}}\Big)^{1-\gamma}}{1-\gamma} + \alpha\frac{g^{1-\mu}}{1-\mu} \ ,$$

where $\gamma > 0$ and $\mu > 0$ denote the parameters of relative risk aversion for private and public consumption and $\psi > 0$ is the Frisch elasticity of labor supply. Note that this specification implies that the marginal rate of substitution between private consumption and labor is independent of consumption. $\alpha \geq 0$ is a preference weight.

Aggregate productivity follows an AR(1) process:

$$\log(z_t) = \varphi \log(z_{t-1}) + \varepsilon_t \ ,$$

where ε_t is i.i.d. $N(0, \sigma_\varepsilon^2)$.

Following Arellano (2008) we employ asymmetric output costs:

$$h(z) = \begin{cases} \phi E(z) & \text{if } z > \phi E(z) \\ z & \text{else,} \end{cases}$$

with $\phi \in (0,1)$.

4.1.2 Parameters

All calibrated parameters and the associated targets and sources are listed in Table 2.

The parameters of the CES production function ω and ρ are set at the same values as in Mendoza and Yue (2012) who choose these parameters to match regression estimates for the domestic/imported intermediate goods' demand elasticity.

Parameter		Parameter Values	Target Statistics/Source
Frisch elasticity	ψ	2.22	Mendoza and Yue (2012)
Risk aversion c	γ	2	Standard RBC value
Risk aversion g	μ	7	Volatility of government consumption ($\sigma_g/\sigma_y = 0.47$)
Weight on public good	α	0.000028	Government consumption share (12.9%)
Weight on imports	ω	0.38	Mendoza and Yue (2012)
CES curvature	ρ	0.65	Mendoza and Yue (2012)
Share of credit-financed imports	ξ	0.495	Working-capital to GDP (6%)
Import price	p^*	2.999	Import share (11.8%)
Risk-free rate	$\overline{R}$	1.01	Standard RBC value
Discount factor	β	0.907	Debt-service to GDP (3.0%)
Re-entry probability	θ	0.2545	Sovereign spread (5.97%)
Output cost	ϕ	0.9869	Sovereign spread pre-default (15.4%)
Recovery rate	η	0.5	Volatility of private spread (4.8%)
Dispersion of idios. shocks	ζ	0.194	Private spread (8.45%)
Persistence of z	φ	0.9743	Autocorrelation of GDP (0.84)
Variance of z shocks	σ_ε	0.00185	Volatility of GDP (4.9%)

Table 2: Parameter Choices

The technology parameters are set to match the empirical autocorrelation and volatility of linear detrended Argentine GDP. The Frisch elasticity is chosen to be 2.22 which is a standard value in international macroeconomics (see also Mendoza and Yue (2012), Neumeyer and Perri (2005) and Cuadra et al. (2010)). The coefficient of risk aversion with respect to private consumption is set to $\gamma = 2$. The coefficient of risk aversion with respect to government consumption is calibrated to $\mu = 7$ to match the volatility of public consumption. The preference parameter that refers to the weight on public consumption is chosen to generate the empirical mean share of public consumption (12.9%).

As in Mendoza and Yue (2012) the share of credit-financed imports is set to match a 6% share of working capital in GDP. The choice of the risk-free interest rate corresponds to a standard value in international macroeconomics. The import price is set to a value that implies a 11.8% share of imports as observed in the data. The parameter ζ which determines the variance of idiosyncratic productivity shocks is chosen to match an annual mean private spread of about 8 percent. Since the recovery rate η is critical for the response of the private interest rate with respect to changes in fundamentals, we calibrate this parameter to generate the empirical standard deviation of private spreads (cf. Table 1).[18]

We follow Arellano (2008) and set the discount factor β so as to match the average public debt service payments as a share of GDP (3%). In our calibration, the probability of re-entering international financial markets after a default equals 0.255 to generate the mean sovereign premium in the data. This value is in the range of what Aguiar and Gopinath (2006) and Arellano (2008) consider. The exogenous output cost is chosen to match the sovereign risk premium in the period before the default takes place (15.4%, cf. Figure 1).

4.2 Results

We now study the quantitative properties of our simulated model economy. First, we analyze the properties of the policy functions to highlight the main economic mechanism that drives the interaction between sovereign and private default risks. Second, we discuss the business-cycle properties of the simulated model economy. Third, we perform an event study and explore the macroeconomic dynamics before

[18]We do not have a good direct measure for the recovery rate on corporate (international) borrowing in Argentina. However, our calibrated value is reasonably close to recovery rates on defaulted U.S. corporate bonds (cf. Jankowitsch et al. (2014)).

and after a sovereign default. Finally, we assess the quantitative importance of the endogenous feedback mechanism between sovereign and private default risks.

4.2.1 Policy Functions

We first shed light on the optimal decision of the government whether to repay or to default on its outstanding external debt and the implied sovereign credit costs. In Figure 2 we consider realizations of aggregate productivity between $\pm$ 1% and show optimal debt and tax policies together with the associated quarterly private interest rate spreads.

The upper left panel of Figure 2 shows the sovereign bond price $q(z, b_+)$. It is evident that, first, the bond price is decreasing in debt. For low levels of debt the government always repays and the bond price is equal to the inverse of the risk-free rate. With higher debt levels, foreign creditors incorporate the rising sovereign default probability in their pricing decision and charge a larger premium on public debt. Second, the bond price decreases if the economy is hit by adverse aggregate productivity shocks. Since a government is less able to service its external debt in bad times, the sovereign premium reflects the increased risk of a sovereign default.

The upper right panel of Figure 2 shows the government's debt policy. For high levels of public external debt and in times of recessions the government becomes borrowing constrained due to prohibitive external credit costs. The lower right panel reveals that the optimal sales tax is increasing in debt and decreasing in aggregate productivity. This pattern implies that fiscal policy is procyclical:[19] In times of recessions the government can become borrowing constrained so that it raises tax rates to finance public expenditures. In default, however, public debt is not repaid such that the government is able to reduce the tax rate. The theoretical prediction regarding the cyclical properties of taxes is in line with the broad empirical literature that shows that developing countries and emerging market economies are characterized by procyclical fiscal policies, see, e.g., Talvi and Vegh (2005), Ilzetzki and Vegh (2008). The cyclical pattern of taxes intensifies the countercyclicality of private interest rates. In a recession, the tax rise amplifies private default risk and increases the private interest rate which is shown in the lower left panel of Figure 2.

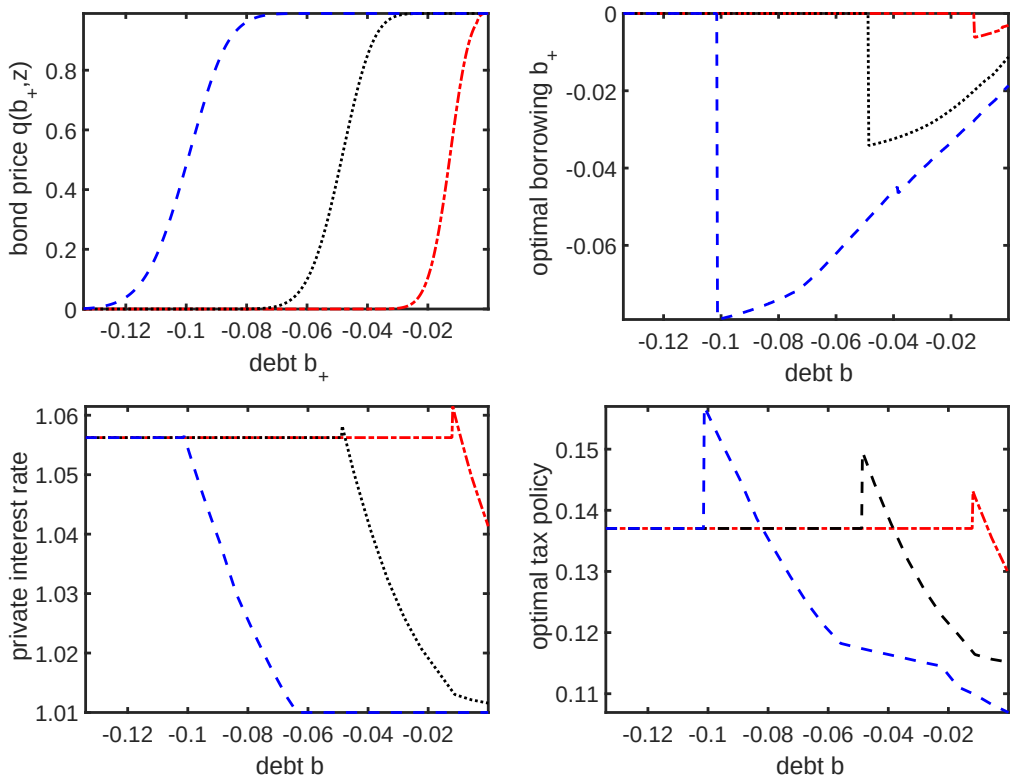

Figure 2: Policy Functions

Notes: This figure shows the sovereign bond price function $q(z, b_+)$, debt policy $\mathcal{B}(z, b, s)$, tax policy $\mathcal{T}(z, b, s)$ and the quarterly private interest rate $\mathcal{R}(z, \tau, s)$ for realizations of aggregate productivity of $+1\%$ (dashed line), 0% (dotted line) and -1% (dashed-dotted line).

	Argentina	Baseline Model	Exogenous Tax Rate	Exogenous Private Interest Rate
Business Cycle Statistics				
$\sigma(y)$	4.94	4.96	2.75	3.81
$\sigma(c)/\sigma(y)$	1.05	0.89	0.79	1.08
$\sigma(g)/\sigma(y)$	0.47	0.50	1.36	0.45
$\sigma(m)/\sigma(y)$	3.09	2.55	2.28	1.70
$\sigma(s)$	2.75	7.63	9.30	7.28
$\sigma(s^p)$	4.81	4.74	2.29	–
$\rho(c,y)$	0.99	0.99	0.99	0.99
$\rho(g,y)$	0.64	0.96	0.86	0.98
$\rho(m,y)$	0.99	0.99	0.99	0.99
$\rho(s,y)$	-0.85	-0.65	-0.45	-0.61
$\rho(s^p,y)$	-0.81	-0.88	-0.86	–
$\rho(s,s^p)$	0.87	0.75	0.52	–
E(s)	5.97	5.75	5.36	5.61
E(s^p)	8.45	8.54	8.78	8.45
E(b/y)	-3.03	-3.01	-2.60	-3.19
E(m/y)	11.76	11.87	11.73	11.45
E(g/y)	12.89	12.89	12.98	13.66
Default Episodes				
Imports	-74.37%	-26.19%	-15.22%	-11.69%
Output	-18.14%	-10.30%	-6.56%	-7.29%
Consumption	-20.09%	-8.87%	-5.16%	-7.41%
Government Spending	-7.82%	-3.75%	-6.38%	-2.64%
Pre-default sovereign spread	15.4	15.97	24.02	15.54

Table 3: Business-Cycle Statistics

Notes: This table reports the business-cycle statistics of output y, consumption c, labor l, public expenditures g, imports m, the annualized sovereign spread s and the annualized private spread s^p. All variables are logged except risk premia before they are linearly detrended. Statistics of the theoretical model refer to a simulation of 50,000 quarters where the first 15,000 quarters are discarded. Default episodes (including one quarter before the default event and the subsequent quarters without external borrowing) are excluded for the business cycle statistics. The first column refers to the Argentine data while the second column refers to the simulated time series generated by the model. The third column refers to the model outcome if the tax rate is exogenously fixed and the fourth column refers to the model outcome if the private interest rate is exogenously fixed. With respect to the default episodes, the table reports the average drop in imports, output, consumption, and government spending in the period in which a default takes place. The last row reports the mean sovereign spread in the period before a default takes place.

4.2.2 Cyclical Properties

In Table 3 we show the business-cycle properties implied by our theoretical framework. We report the statistical moments based on simulated time series that exclude default events. All variables are logged before they are linearly detrended, except the tax rate, the sovereign premium, and the private premium.

A comparison of the simulated and the empirical cyclical properties reveals that our model captures the co-movements between the variables and the overall macroeconomic volatility. In particular, the model replicates the countercylicality of sovereign and private premia and the procyclicality of consumption, imports, and public expenditures.

The model also mimics the empirical fact that imports are more volatile than output. While the model replicates the volatility of the private premium, it overstates the standard deviation of the sovereign premium. The high volatility of sovereign credit costs is due to the occurrence of "near default states" in which adverse realizations of aggregate productivity substantially increase the default risk so that foreign creditors charge high sovereign premia. In spite of high credit costs, the government finds it still optimal to repay because the exclusion from international financial markets imposes a severe punishment.

4.2.3 Dynamics Around Default

To understand the interaction of sovereign and private default risk and their impact on macroeconomic outcomes, we perform an event study and show the dynamics of the economy six quarters before and after a sovereign default. We assume that the government is in a good credit standing in $t<0$ but defaults at date $t=0$. In Figure 3 the solid lines show the percentage deviations from a linear trend for output, labor, imports, consumption, public expenditures and aggregate productivity while the tax rate and the sovereign and private spreads are in percent. In order to compare the model with the Argentine default episode, Table 3 reports the percentage deviations of imports, output, consumption, and government spending in the default period as well as the mean sovereign spread in the period before a default takes place.

The dynamic patterns suggest that the economy is in a recession prior to a sovereign default. Decreasing aggregate productivity leads to a fall in output, raising the risk of a sovereign default which is reflected by the sovereign interest spread in the quarters before the default takes place. Due to high credit costs, the government becomes borrowing constrained and raises the tax rate to finance public expenditures. This leads to an endogenous amplification mechanism: Higher tax rates in a recession lower the profitability of private

[19] A similar procyclical pattern can be observed in the policy functions for government expenditures.

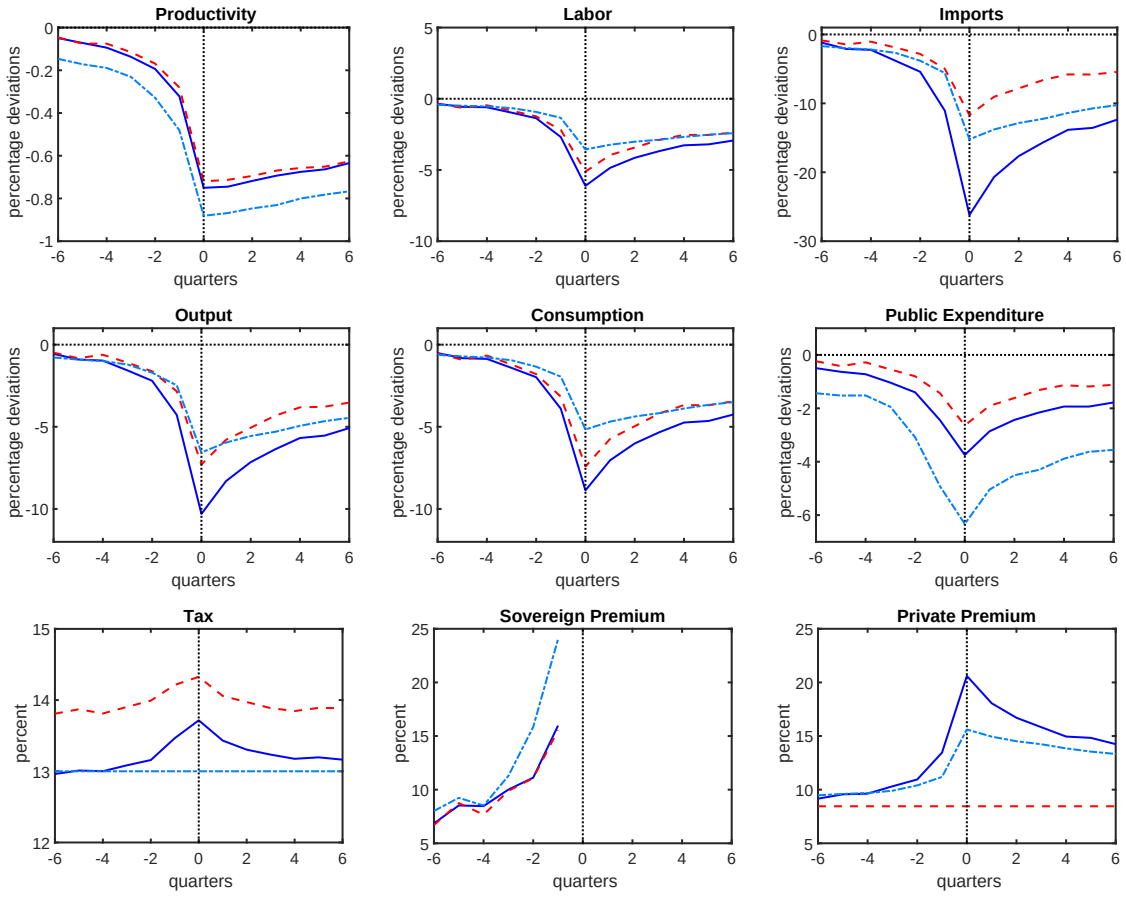

Figure 3: Default Event

Notes: This figure shows the dynamic pattern of productivity z, labor l, imports m, output y, consumption c, public expenditures g, tax rate τ, the annualized sovereign spread s and the annualized private spread s^p six quarters before and after a default. The government is in a good credit standing in $t < 0$ and defaults at quarter $t = 0$. All variables are shown as percentage deviations from their linear trend, except the tax rate and the premia which are shown in percent, based on a simulation of 50,000 quarters where the first 15,000 quarters are discarded. For all variables the mean values over all default events are shown. The dashed-dotted lines refer to the dynamics if the tax rate is exogenously fixed and the dashed lines refer to the dynamics if the private interest rate is exogenously fixed.

firms so that the risk of a private default increases. Foreign creditors incorporate the default risk in their pricing decision and charge a larger premium on private external debt. Import demand falls and the recession deepens. In turn, low output reinforces the risk of a sovereign default, and the sovereign premium increases further. After the default, the government is excluded from international financial markets. Since debt service obligations are not fulfilled, the government budget constraint relaxes such that the tax rate can be reduced. The private premium decreases and imports as well as output recover.

Overall, the model generates dynamics around default events that are in line with the empirical evidence observed in Argentina. In particular, given the calibrated sovereign premium of 15% in the period before the default, the model replicates the high private premium of about 20% as seen in the Argentine data. Note that our theoretical model assumes that after a sovereign default the government is excluded from international financial markets; this is why the sovereign premium is infinite. The increase in the private premium, however, is of a transitory nature which is in line with the empirical pattern in Argentina after the default in 2002.

The model also replicates the facts that the import drop is a multiple of the output drop and that the fall in government spending is less pronounced than the fall in private consumption. Note, however, that the model underestimates the severity of the recession, see Table 3. During the Argentine default output, imports, consumption and government spending decreased by 18.1%, 74.4%, 20.1% and 7.8%, respectively. In the simulated economy the recession is less severe and we observe a decline of 10.3% for output, 26.2% for imports, 8.9% for consumption and 3.8% for government expenditures. The empirical patterns of these variables are affected by additional factors that are not included in our model, such as exchange rate dynamics and the sovereign-bank nexus as emphasized in, e.g., Engler and Große-Steffen (2016), Niemann and Pichler (2016), and Sosa-Padilla (2012). Therefore, our model isolates the endogenous amplification generated by the dynamic interaction between sovereign and private default risks through the response of fiscal policy to adverse productivity shocks.

4.2.4 The Feedback Mechanism between Fiscal Policy and Default Risks

To study the quantitative importance of the dynamic feedback mechanism between sovereign and private default risks through fiscal policy, we first focus on the impact of tax changes on the evolution of the private interest rate. The private interest rate is determined by the tax rate as well as aggregate productivity via the "net productivity" variable $\tilde{z} \equiv (1-\tau)z$. We decompose the variance of changes in $\tilde{z}$ into a tax, a productivity and a covariance component: $\sigma^2_{\tilde{z}} = \sigma^2_{1-\tau} + \sigma^2_z + cov(1-\tau, z)$. Our simulation results indicate that the tax component explains approximately 63% and the productivity component explains approx-

imately 7% of the variance of $\tilde{z}$.

To explore the role of fiscal policy, we conduct a counterfactual experiment in which we shut down the endogenous tax response and fix the tax rate at the simulated mean of the benchmark model (13%). The dashed-dotted lines in Figure 3 refer to the associated default dynamics. As in the baseline model, default events are associated with low aggregate productivity. Note, however, that with an exogenous tax rate, default events are characterized by worse productivity realizations compared to the baseline model (solid line). Low productivity raises the private premium which reduces imports. But since the amplification mechanism is shut down by the fixed tax rate, the increase in the private interest rate and the downturn in imports are smaller than in the baseline model in spite of worse productivity realizations. Consequently, the recession is less severe when the tax rate is fixed. Furthermore, the recession starts later: The downturn accelerates only one quarter prior to the default whereas in the baseline model output starts to fall significantly 3 quarters prior to the default. However, the recovery after the default is slower if the tax rate is exogenously fixed. These findings highlight that the endogenous response of tax policy deepens the recession before a default but facilitates a faster recovery after the default.

The third column of Table 3 summarizes the business-cycle statistics associated with a fixed tax rate. Clearly, without the endogenous amplification through fiscal policy, output, the private interest rate and imports become less volatile. Moreover, the sovereign and private premium are less correlated over time. On the other hand, the sovereign premium and government expenditures are more volatile compared to the baseline model. With an exogenous tax rate, government expenditures are more responsive to changes in net borrowing and therefore more responsive to changes in sovereign default risk. In a recession, government expenditures fall stronger than consumption, distorting the ratio of marginal utilities and therefore increases the default incentives of the benevolent government.

To assess the role of endogenous private default risk, we conduct another counterfactual experiment in which we shut down corporate default risk and set the private interest rate at the empirically observed value of 8.45%.[20] The dashed lines in Figure 3 show the dynamics around a default event associated with a fixed private interest rate. Again, low aggregate productivity increases sovereign default risk and raises the sovereign risk premium. The government becomes borrowing constrained and increases the tax rate to finance public expenditures. Since the private interest rate is exogenously fixed, the amplification mechanism is absent such that imports fall less strongly and the recession is less severe compared to the baseline model (solid lines).

The fourth column of Table 3 shows that with a fixed private interest rate, output and

[20]We adjust the exogenous price for intermediate imports to 1.14 to match the import share in the data.

imports become less volatile. Because the private interest rate does not react to fiscal policy, the government can implement higher tax rates without distorting the demand for intermediate imports. Hence, the default incentives of the government are lower and the government can support higher debt and higher government expenditures.

5 Conclusions

In this paper we analyze how sovereign and private default risks interact. We develop a stochastic general equilibrium model of a small open economy featuring endogenous private and sovereign default risks. Private sector firms use imperfectly substitutable domestic and imported intermediate goods to produce a final consumption good, where part of the imports need to be financed by external debt. The economy also features a benevolent government providing a public good, financed by taxing firms and borrowing from abroad. The model can account for several empirical regularities in emerging market economies, namely countercyclical private and sovereign risk premia, procyclical fiscal policy, and deep recessions with large drops in imports during default events.

Our results suggest that fiscal policy creates a link between sovereign and private default risks and provides an amplification mechanism reinforcing the effects of adverse productivity shocks. Whenever the government faces higher borrowing costs in a recession, it raises tax rates so as to reduce external credit costs which decreases firms' profitability and leads to higher private default risk. In turn, firms cut their demand for imported inputs which deepens the recession. While our study highlights this particular mechanism, other channels may also be relevant for future research. For instance, little is known about how exchange rate movements (Asonuma, 2014), debt renegotiations (Yue, 2010), long run growth (Gorneman, 2014) or secondary debt markets interact with private and sovereign credit risks.

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Appendix A: Numerical Algorithm

The private-sector equilibrium can be calculated on a grid for (z, τ), without knowing the government's policy functions. These solutions are used to solve for the government's problem and the risk-neutral pricing of government bonds via value function iteration.

The numerical algorithm builds on Hatchondo et al. (2010) and employs cubic spline interpolations so that optimal policies are chosen from a continuous set and productivity realizations are allowed that do not lie on the grid. We approximate the equilibrium as the equilibrium of the finite-horizon economy and iterate simultaneous on the value and the bond price functions.

We define evenly distributed grid vectors for bond holdings $b \in [\underline{b}, \bar{b}]$ with 25 grid points and productivity realizations $z \in [\underline{z}, \bar{z}]$ with 19 grid points. Let $V^{N(0)}(z, b)$ and $V^{D(0)}(z)$ denote the initial guesses for the value functions. For every grid point $(z, b) \in [\underline{z}, \bar{z}] \times [\underline{b}, \bar{b}]$ and given the initial guesses $V^{N(0)}(z, b)$ and $V^{D(0)}(z)$ we first find candidate values for $\tau^{(0)}$ and $b_+^{(0)}$ by employing a global search procedure. These candidate values are then taken as initial guesses for the FORTRAN optimization routine BCPOL from the IMSL library to find $\tau^{(0)}$ and $b_+^{(0)}$ via (8), (9) where $V_{(0)}^0(z, b, s)$ satisfies equation (7). Given the initial guess, equations (10) and (11) determine the the default probability $\lambda^{(0)}(z, b_+^{(0)})$ and the bond price function $q^{(0)}(z, b_+^{(0)})$, respectively. Expected continuation values are computed using Gauss-Hermite quadrature points and weights. To evaluate the expected continuation values for policies and productivity realizations that do not lie on the grid we employ cubic spline interpolations using the algorithm of Akima (1996). The solutions found at each grid point are used to update the value functions $V^{N(1)}(z, b)$ and $V^{D(1)}(z)$. We iterate until the value functions converge.

Appendix B: Further Empirical Findings

Table 4 reports the business-cycle statistics of the countries contained in our sample. Default episodes are excluded. We observe that emerging market economies are more volatile than developed economies. Emerging markets also show excess volatility of private and government consumption, whereas in developed economies only government consumption is more volatile than GDP on average. Furthermore, in both country groups imports and exports are on average two to three times more volatile than GDP. Our observations are in line with results found by Neumeyer and Perri (2005).

	$\sigma(y)$	$\frac{\sigma(c)}{\sigma(y)}$	$\frac{\sigma(g)}{\sigma(y)}$	$\frac{\sigma(m)}{\sigma(y)}$	$\frac{\sigma(x)}{\sigma(y)}$
Argentina	4.94	1.05	0.47	3.09	1.49
Brazil	3.22	1.57	0.92	5.67	3.11
Chile	2.65	1.62	1.30	3.74	2.79
Ecuador	1.93	0.66	0.85	2.98	2.47
Korea	13.08	0.89	0.45	1.13	0.93
Malaysia	4.89	1.23	1.74	2.50	2.68
Mexico	3.05	1.26	1.12	4.48	3.61
Peru	14.34	0.81	1.53	1.70	1.32
Philippines	7.57	0.62	1.71	2.22	1.45
Russia	5.25	1.00	1.13	2.86	1.52
Venezuela	7.71	0.73	0.59	2.59	1.53
Australia	2.35	1.07	1.15	4.71	4.16
Canada	3.22	0.80	1.20	2.85	4.76
Netherlands	4.07	1.37	0.64	1.76	1.60
New Zealand	3.65	1.04	1.02	2.05	1.54
Sweden	3.07	0.60	0.41	2.57	3.01
Switzerland	2.22	0.60	2.67	2.27	2.49
Emerging Markets	6.24	1.04	1.07	3.00	2.08
Developed Economies	3.10	0.91	1.18	2.70	2.93

Table 4: Business-Cycle Statistics

Notes: y refers to real GDP, c and g denote real consumption and real public expenditures, respectively. m and x are real imports and exports. All time series are log-linearly detrended.

Appendix C: Data Sources and Calculations

The sample of emerging markets economies is chosen according to JP Morgan's characterization and data availability. More precisely, we restrict the sample to include countries for which at least 10 years of quarterly data are available until 2013Q2. Korea is the only exception from this rule. We add Korea because it is also in the sample of Neumeyer and Perri (2005).

All data are taken from national sources if available, otherwise we use data from international organizations. Only in cases where no other source was available we use commercial data providers like Oxford Economics. Detailed information on data sources and adjustments are summarized in the tables below.

When data are not seasonally adjusted, we employ the Census X12 method from the U.S. Census Bureau. Most nominal time series are deflated using the GDP deflator. For imports and exports we use the import and export price deflators.
For the calculation of correlations and volatilities we are interested in the cyclical components of the respective series. In order to get the cyclical components of GDP and imports, we subtract a linear trend from the logged series. For the risk premia the raw series are demeaned.

We follow Neumeyer and Perri (2005) and Arellano and Kocherlakota (2014) and use the emerging markets sovereign premia provided by JP Morgan. For developed economies, sovereign premia are calculated by subtracting the medium term US bond yield from the respective countries' medium term bond interest rate.

In most cases private premia are calculated by subtracting the local currency deposit rate from the lending rate. Whenever the US$ lending rate is available, a US government debt interest rate with similar maturity is used as the risk-free rate.[21]

Tables 5 and 6 give more details on data sources and transformations, where 'SA' stands for 'seasonally adjusted' and 'R' denotes series transformed into real terms.

In order to show that total imports are an acceptable proxy for intermediate good imports we calculate their share in total imports. In this we follow Mendoza and Yue (2012) and define intermediate goods imports as all imports falling into the following product categories of the COMSTAT dataset: (111*) Food and beverages, primary, mainly for industry; (121*) Food and beverages, processed, mainly for industry; (21*) Industrial supplies not elsewhere specified, primary; (22*) Industrial supplies not elsewhere specified, processed; (31*) Fuels and lubricants, primary; (322*) Fuels and lubricants, processed (other than motor spirit); (42*) Parts and accessories of capital goods (except transport equipment); (53*) Parts and accessories of transport equipment. On average these imports are responsible for around 58% of total imports in emerging economies and around 48% in

[21] See Table 6 for a detailed description of how the risk premia are calculated.

developed economies.

Country	Data Source	Sample	Currency	Adjustment	Basis Year Deflator	Information
Argentina	Ministero de Economica y Production MECON	Q1 1993-Q2 2013	NCU		1993	
Brazil	Instituto Brasileiro de Geografia e Estatistica	Q1 1995 - Q2 2013	NCU	SA	2005	
Chile	OECD Outlook	Q1 1995-Q2 2013	NCU		2008	GDP deflator is calculated from nominal and real GDP.
Ecuador	Banco Central del Ecuador	Q1 1990-Q1 2012	US-$	SA	2000	Discontinued after Q1 2012
Korea	Bank of Korea	Q2 1972-Q2 2013	NCU		2005	
Malaysia	Department of Statistics, Malaysia	Q1 1991-Q2 2013	NCU	R	2005	GDP deflator is taken from Oxford Economics.
Mexico	Instituto Nacional de Estadistica, Geografia e Informatica, Mexico	Q1 1993-Q2 2013	NCU		2008	
Peru	Central Reserve Bank of Peru	Q1 1980-Q2 2013	NCU	SA	1994	GDP deflator is calculated from nominal and real GDP.
Philippines	National Statistical Coordination Board (NSCB), Philippines	Q1 1981-Q2 2013	NCU	SA,R	2000	
Russia	Federal State Statistics Service, Russia	Q4 1999-Q2 2013	NCU	SA,R	2005	GDP deflator is taken from Oxford Economics.
Venezuela	Banco Central de Venezuela	Q1 1998-Q2 2008	NCU	SA	1997	GDP deflator is taken from Oxford Economics.
Australia	Australian Bureau of Statistics	Q2 1972-Q2 2013	NCU		2011-12	
Canada	Statistics Canada (CANSIM)	Q1 1981-Q2 2013	NCU		2007	
Netherlands	Statistics Netherland (CBS)	Q1 1988-Q2 2013	NCU		2005	
New Zealand	Statistics New Zealand	Q2 1987-Q2 2013	NCU		1995-96	
Sweden	Statistics Sweden	Q1 1993-Q2 2013	NCU		2012	
Switzerland	State Secretariat for Economic Affairs (SECO), Switzerland	Q1 1980-Q2 2013	NCU		2005	

Table 5: Data Sources for GDP and Imports.

Country	Data Source Sovereign Premium	Sample Sovereign Premium	Sample Lending Rate	Sample Deposit Rate	Lending Rate	Risk Free Rate
Argentina	JP Morgan, EMBI Global	Q1 1994- Q2 2013	Q2 1993- Q2 2013	Q2 1993- Q2 2013	US$ denominated with 30 days maturity.	US-Bond with 3 month maturity.
Brazil	JP Morgan, EMBI Global	Q3 1994- Q2 2013	Q1 1997 - Q2 2013	Q4 1982- Q2 2013	Domestic currency with average maturity.	Domestic currency borrowing rate with average maturity.
Chile	JP Morgan, EMBI Global	Q3 1999- Q2 2013	Q3 1992- Q2 2013	Q3 1992- Q2 2013	US$ denominated with 30-89 days maturity.	US-Bond with 3 month maturity.
Ecuador	JP Morgan, EMBI Global	Q2 1995- Q2 2013	Q1 1980- Q3 2008	Q1 1983- Q4 2011	Domestic currency with 90-172 days maturity.	Domestic currency borrowing rate with 30-83 days maturity.
Korea	JP Morgan, EMBI Global	Q1 1994- Q3 2002	Q3 1980- Q2 2013	Q2 1972- Q2 2013	Domestic currency with maturity less 1 year.	Domestic currency borrowing rate with maturity 1-2 years.
Malaysia	JP Morgan, EMBI Global	Q1 1997- Q2 2013	Q4 1986- Q2 2013	Q2 1972- Q2 2013	Domestic currency with 3 month maturity.	Domestic currency borrowing rate with average maturity.
Mexico	JP Morgan, EMBI Global	Q1 1994- Q2 2013	Q4 1993- Q2 2013	Q1 1976- Q2 2013	Domestic currency with unknown maturity.	Domestic currency borrowing rate with 60 days maturity.
Peru	JP Morgan, EMBI Global	Q2 1997- Q2 2013	Q1 1992- Q2 2013	Q1 1992- Q2 2013	US$ denominated with maturity less than 1 year.	US-Bond with 3 month maturity.
Philippines	JP Morgan, EMBI Global	Q1 1998- Q2 2013	Q1 1976- Q2 2013	Q1 1976- Q2 2013	Domestic currency with average maturity.	Domestic currency borrowing rate with 61-90 days maturity.
Russia	JP Morgan, EMBI Global	Q1 1998- Q2 2013	Q1 1998- Q2 2013	Q1 1998- Q2 2013	Domestic currency with less than 1 year maturity.	Domestic currency borrowing rate with less than 1 year maturity.
Venezuela	JP Morgan, EMBI Global	Q1 1994- Q2 2013	Q1 1984- Q2 2013	Q1 1984- Q2 2013	Domestic currency with average maturity.	Domestic currency borrowing rate with 90 days maturity.
Australia	IFS	Q2 1972- Q2 2013	Q2 1972- Q2 2013	Q2 1972- Q2 2013	SP: Government Bond with 15 year maturity	SP: US bond with 10 years maturity.
Canada	IFS	Q2 1972- Q2 2013	Q2 1972- Q2 2013	Q2 1972- Q2 2013	SP: Government Bond with 10 year maturity	SP: US bond with 10 years maturity.
Netherlands	IFS	Q2 1972- Q2 2013	Q1 1980- Q2 2013	Q1 1981- Q2 2013	SP: Government Bond with 10 year maturity	SP: US bond with 10 years maturity.
New Zealand	IFS	Q2 1972- Q2 2013	Q2 1972- Q2 2013	Q2 1972- Q2 2013	SP: Government Bond with 5 year maturity	SP: US bond with 3 years maturity.
Sweden	IFS	Q3 1986- Q2 2013	Q2 1972- Q2 2013	Q2 1972- Q2 2013	SP: Government Bond with 10-15 year maturity	SP: US bond with 10 years maturity.
Switzerland	IFS	Q2 1972- Q2 2013	Q1 1981- Q2 2013	Q1 1981- Q2 2013	SP: Government Bond with more than 10 year maturity	SP: US bond with 10 years maturity.

Table 6: Data Sources for Interest Rates.