External Debt, Defaults and Exchange Rate Dynamics*

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Abstract

Emerging countries experience exchange rate depreciations around defaults. This paper explores this observed evidence within a dynamic stochastic general equilibrium model in which bond issuances in local and foreign currencies are explicitly embedded and exchange rate and default risk are determined endogenously. Our quantitative analysis replicates the link between exchange rate depreciation and default probability around defaults. In pre-default periods, interactions of exchange rate depreciation originated by lower traded goods income with its large share of foreign currency denominated debt trigger default. In post-default periods, exchange rate in turn, depreciates further due to output costs and loss in market access.

JEL Classification Codes: E43; F32; F34; G12
Key words: Currency composition; Exchange Rate Dynamics; External Debt; Sovereign default;

1 Introduction

Emerging countries experience exchange rate depreciations around the default events. This paper attempts to explore this observed evidence within a dynamic stochastic general equilibrium model in which bond issuance in local and foreign currencies are explicitly embedded and exchange rate and default risk are determined endogenously. Our quantitative analysis using data of Argentina, Russia and Uruguay replicates link between exchange rate depreciation and default probability before and after defaults. In pre-default periods, a combination of both exchange rate depreciation originated by

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lower traded goods income and a large share of foreign currency denominated debt triggers default choice of emerging countries. In post-default periods, exchange rate in turn, depreciates further due to output costs of defaulting and loss of market access.

This paper deals with endogenous exchange rate dynamics before and after default in a standard dynamic model of defaultable debt. Exchange rate, defined as relative CPI between the sovereign and the creditor, interacts with default risk (default choice) of the sovereign. Evidence suggests that the exchange rate tends to depreciate in both pre-default and post-default periods. Thus, it clearly reflects that before default, the exchange rate depreciaton increases a burden of payments for the sovereign triggering a default, and default indicating being forced to be financial auturky, leads to further exchange rate depreciation in post-default period.

The present paper seeks to explore exchange rate depreciations during both pre- and post-default periods. In the model, before default, the sovereign receiving a series of bad traded goods income shocks, tends to accumulate more debt and faces exchange rate depreciation. Since a majority of debt is denominated in foreign currency, this in turn, increases the burden of payments in terms of local currency increasing default probability and forcing the sovereign to default. Once the sovereign declares default, it suffers output costs due to default and loses access to the market. By defaulting, the sovereign perfers to have higher consumption of traded goods indicating lower marginal utility of consumption which leads to both higher price of non-traded goods and higher overall price level. Thus, it ends up with a further depreciation of exchange rate. This mechanism drives the equilibrium depreciation of exchange rate in the model and it is a plausible explanation of observed pattern in the data. Hence, the model is able to replicate the stylized facts of exchange rate and defaults.

We embed the endogenous exchange rate dynamics in a dynamic sovereign debt model with endogenous defaults where an emerging country is subject to exogenous shocks of both tradable and non-tradable goods. This part of the model builds on recent quantitative analysis of sovereign debt such as Aguiar and Gopinath (2006), Arellano (2008), and Tomz and Wright (2007) which are based on a classical setup of Eaton and Gersovitz (1981). Moreover, a "representative"creditor is also risk-averse and faces exogenous shocks of both tradable and non-tradable goods as in Borri and Verdelhan (2009), and Lizarazo (2013). Before default, a combination of both exchange rate depreciation originated by lower traded goods income and large share of foreign currency denominated debt leads to default choice of emerging countries. In post-default periods, exchange rate in turn, deprecaites further due to output costs of defaulting and being forced to be financially auturky.

The rest of the paper is structured as follows. Section 2 reviews three strands of literature. Section 3 overviews stylized fact and emeprical results on exchange rate dynamics and sovereign defaults. We provide our stochastic dynamic general equilibrium model in Section 4. Recursive equilibrium of the model is defined in Section 5. Quantitative analysis of the model is shown in Section 6. Model implications are discussed in in Section 7. A short conclusion summarizes the discussion. A computation algorithm is provided in Appendix A.

2 Literature Review

Our paper builds on some strands of literature. First of all, this paper is related to the literature of sovereign debt and defaults which extend a classical model of Eaton and Gersovitz (1981) and applies quantitative analysis. Arellano (2008), and Aguiar and Gopinath (2006) explore the connection between endogenous default, interest rates and income fluctuations in a dynamic model of a small open economy and generate empirical regularities such as counter cyclical interest rates and countercyclical net exports in emerging markets. Alfaro and Kanczuk (2005) and Hatchodo et al (2009) introduce political turnovers by assuming heterogenous borrowers in model of sovereign debts. Asonuma (2012), Benjamin and Wright (2009), Bi (2008), and Yue (2010) model debt renegotiation after defaults and explain observed evidences on debt restructurings. However, these models do not consider the link between sovereign defaults and exchange rate dynamics.

Other strand of literature studies the relation between sovereign defaults and exchange rates. Arellano and Heathcote (2010) explore what determines credit limit and how these vary across exchange rate regime by building a model in which the government responds to shocks by adjusting domestic monetary policy and foreign borrowing.[1] Bussiere, Fratzcher and Koeniger (2003) link the exchange rate uncertainty in foreign currency debt to solvency and the choice of debt maturity, and find that a currency mismatch can exacerbate a maturity mismatch and increase output volatility. Jeanne (2003) theoretically explains a relationship between monetary credibility under the fixed regime and the currency composition of debt such that increase in probability of devaluation induces both domestic borrowers and the government to borrow in foreign currency. Our paper differs in that we

[1] Jahjah et al (2012) empirically analyze how exchange rate policy affects the supply and pricing of sovereign bonds in developing countries.

mainly focus on an interaction between default choices and exchange rate dynamics.

The third stream of literature discusses sovereign debt and risk-averse investor. Borri and Verdelhan (2009), Lizarazo (2013), Presno and Puozo (2011) study the case of risk averse lenders and show that risk aversion allows the model to generate speads larger than default probabilities, which is a feature of the data. Borri and Verdelhan (2009) consider risk aversion with external habit preference, whereas Lizarazo (2013) assumes decreasing absolute risk aversion (DARA). Presno and Puozo (2011) introduce fears about model misspecication for the lenders. What distinguishes current paper with these papers is that we incorporate exchange rate determination together with exchange rate risk.

Lastly, this paper also contributes to the literature of currency compositions of external debt. Jeanne (2003) claims that unpredictable monetary policy makes domestic borrowers and the government unsure about the future real value of their domestic currency debts and may induce them to dollarize their liabilities. Moreover, Eichengreen, Hausmann and Panizza (2004) suggest that an inability to borrow abroad in domestic currency ("original sin") has at least as much to do with structure and operation of the international financial system as with weakness of policies and institutions. Furthermore, Burger and Warnock (2006) stress that by improving policy performance and strenghening institutions, emerging economies may develop local curency bond market, reduce their currency mismatch and lessen the likelihood of future crises.[2][3][4] This paper improves these papers by explaining how behavior of foreign creditors to avoid the exchange rate risk leads to encourage lending in foreign currency rather than local currency.[5]

3 Stylized facts and empirical findings

In this section, we provide observed evidences on exchange rate dynamics and sovereign default. From recent sovereign default and restructuring episodes, there exists an empirical link between exchange

[2] Aghion, Bacchetta, and Banerjee (2004) propose the following: borrowers can use unsecured debt in domestic currency as a collateral to obtain a loan in foreign currency. This reduces the interest rate on foreign currency debt since, in the case of a crisis, the loss is partially transferred to lenders in domestic currency.

[3] In addition, Corsetti and Mackowiak (2004) show how monetary and fiscal policies, including maturity and currency denomination of debt, interact to determine dynamic response of the economy and magnitude of devaluation and inflation.

[4] Chamon and Hausmann (2004) explore an interplay between an individual borrower's choices for liability denomination through the effect on optimal monetary response of the central bank, given those choices.

[5] We relate our paper to the literature of portfolio allocation between an emerging market economy and an advance economy as in Devereux and Sutherland (2009) and Tille and Van Wincoop (2010) which examine determinants of an optimal risk-sharing allocations. Coeurdacier and Gourinchas (2013) consider international portfolio with real exchange rate and non financial risks that account for observed levels of equity home bias.

rate Empirical findings also strengthen the observed link.

3.1 Stylized facts on exchange rate dynamics and sovereign defaults

Figure 1 displays fluctuations of real exchange rates against the US dollar before and after defaults/annoucements of restructurings for 16 episodes in 1998-2012.[6][7] Exchange rates are normalized with respect to level at time of defaults or annoucements of restructurings. We observe an empirical link between the exchange rate depreciation and default risk (default choice): on one hand, the exchange rate depreciaton increases a burden of payments for a sovereign country and triggers a default and on the other hand, the country's annoucement of defaut or restructuring leads to further exchange rate depreciation. Exceptional cases are Ecuador in 2008 for pre-default period and Dominican Republic for post-default period.[8][9]

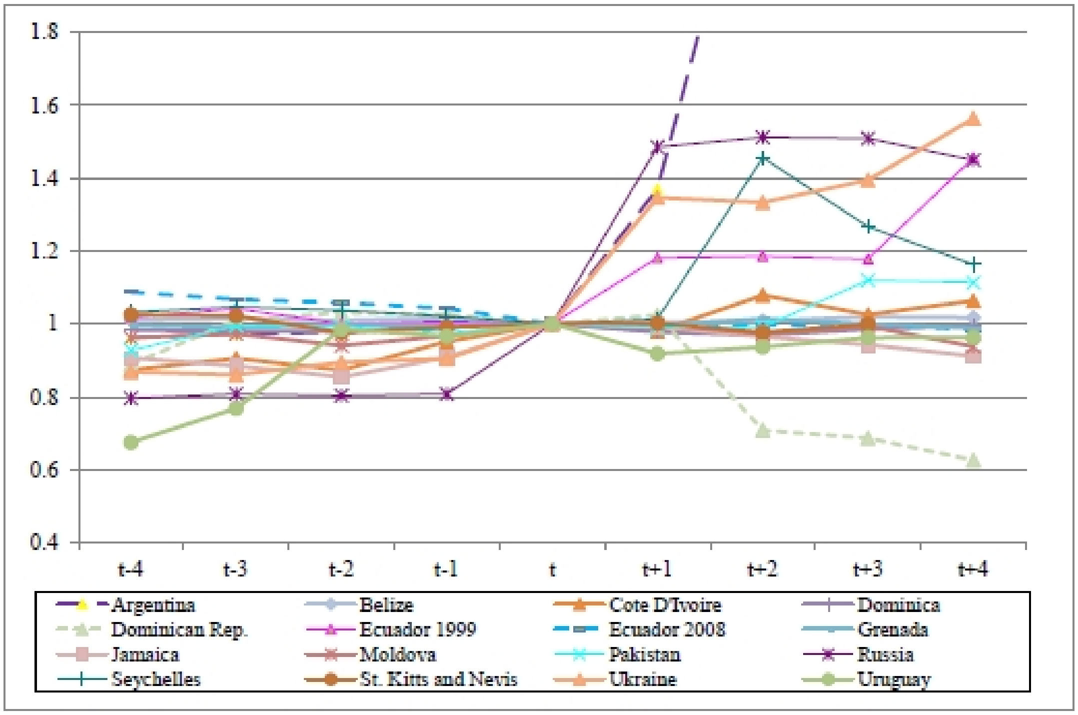
Figure 1: Real Exchange Rates against the US dollar before and after Defaults/Restructurings

[6] We exclude episodes of default/debt restructurings of debt held by official sector. Cases of Antigua and Barduba, Serbia and Montenegro, and Iraq are not included due to lack of quarterly data of exchange rate and CPI. Greece case is not included due to an absence of exchange rate against euro associated with membership of Eurozone.

[7] Following definition of preemptive and post-default restructurings in Asonuma and Trebesch (2013), we set t at time of defaults for post-default restructuring cases and at time of announcements for preemptive restructuring cases.

[8] Ecuador 2008 case can be treated as exceptional since Ecuador announced in December 2008 that the government missed an interest payment of $30.6 million on its $510 million of 12% global bonds due in 2012. The authorities announced in November 2008 that the 2012 and the 2030 securities are"illegal" and "illegitimate." Thus, It was considered that default was triggered by political decision rather than solvency or liquidity issues.

[9] Dominican Repubic in 2004-5 is also considered as unusual case since Dominican Republic announced its debt restructuring on private debt in April 2004 associated with restructuring on official sector debt. However, its debt restructurings had been proceeded in two independent approaches; for bank loans, on August 2004, Domnican Republic started its renegotaitons creditors. However, it missed its payments on February 2005, and launched the final exchange offer on June 2005 which was completed later on October 2005. On the contrary, for external bonds, preemptive restructuring was initiated in January 2005, and Dominican Republic launched the final exchange offer on April 2005 which was completed later on May 2005.



Source: Asonuma and Trebesch (2013), Cruses and Trebesch (2011), IMF IFS

3.2 Empirical analysis of the link

With our sample of 16 episodes, empirical analysis examines a relationship between exchange rate depreciations and default probability (default choice) in both pre-default and post-default periods. First in pre-default period, we test whether actual level of exchange rates at previous period normalized with respect to the level at defaults/annoucement of restructurings, leads to increase in default probability. For a proxy for default probability, we use sovereign credit ratings which are transformed into discrete forms following Sy (2002).[10][11] We apply a two-step least square estimation using the US GDP deviation from the trend as an instrument.

$$Rating_t = ER_{t-1}\beta + Z_{t-1}\gamma + \varepsilon_{1,t} \quad (1)$$

[10]The alternative approach is to use a binary variable showing default and non-default choices and to apply a probit estimation. This method also provides us results similar to Table 1 with smaller degree of significance. Our approach enables us to receive benefits of better fits derived by sovereign risk ratings which capture high degree of variation in default probability.

[11]Sy (2002) convert S&P's and Moody's ratings to numerical values using a linear scale from 0 to 20 with S.D. and CC/Ca ratings corresponding to values of 0 and 1, respectively, and AAA/Aaa ratings being assigned a value of 20.

where ER_{t-1} and Z_{t-1} are estimates of lagged exchange rates and other explanatory variables which are composed of country-specific factors such as GDP deviation from the trend and debt-to-GDP ratio both entered as lagged, and concurrent global liquidity factors such as 1-year LIBOR rate and political risk rating.

Fixed effect regresion results confirm that exchange rate depreciation is linked to increase in default probability shown in Table 1; depreciations expressed by higher levels of exchange rates lead to lower levels of ratings meaning higher default probability. Given heterogeneity in sovereign risk ratings before defaults, we rely on a fixed effect regression rather than a pooled regression. This negative relationship is robust even after controling concurrent global liquidity and domestic political factors.

Table 1: Regression results for Pre-Default Period

	(A) Pooled reg.	(B) Baseline	(C) Global factors	(D) Political Factors
	Pooled	Fixed effect	Fixed effect	Fixed effect
Exchange rate, lagged	-14.5*** (2.07)	-13.3*** (2.96)	-10.4*** (3.05)	-7.58*** (2.70)
GDP deviation, lagged	0.10 (0.06)	0.22*** (0.07)	0.16** (0.07)	0.11 (0.06)
Debt-to-GDP, lagged	-0.01 (0.01)	0.02 (0.13)	-0.00 (0.01)	-0.01 (0.01)
LIBOR 1-year	-	-	0.48** (0.19)	0.82 (0.17)
Political risks rating*1	-	-	-	0.11* (0.06)
Samples	68	68	68	55
Adj-R^2	0.42	0.96	0.96	0.98
F-statistics	16.9	118.6	121.7	177.0

Note: *, **, *** denote sifnificant at 10%, 5%, and 1%, respectively.

*1 Political risk rating is from annual average of monthly PRC composite risk rating from 1985-2012.

Next, for post-default period, we analyze whether default choices of sovereigns influence exchange rate depreciation in the future. The same approach of a two-step least square regression is applied using credit ratings of other emerging countries in other region with a similar size and degree of openness. Sovereign risk ratings are treated as indicators of default choices;[12]

$$ER_t = Rating_{t-1}\beta + Z_{t-1}\gamma + \varepsilon_{2,t} \tag{2}$$

From pooled regresion results in Table 2, we show that sovereigns' default choices expressed as lower credit ratings trigger exchange rate depreciations. As exchange rates are normalized to levels at time of defaults, a pooled regression provides us enough results. By controlling global liquidity, business cycle factors, as well as sovereigns' political factors, we still find that this relationship is robust.

Table 2: Regression results for Post-Default Period

	(A) Baseline	(B) Global factors	(C) Political Factors
	Pooled	Pooled	Pooled
Constant	1.15*** (0.04)	1.13*** (0.03)	1.24*** (0.04)
Rating, lagged	-0.09*** (0.02)	-0.13*** (0.02)	-0.10*** (0.02)
GDP deviation, lagged	-0.04*** (0.01)	-0.05*** (0.01)	-0.02** (0.01)
Debt-to-GDP, lagged	0.003*** (0.001)	0.004*** (0.001)	-0.01 (0.01)
US GDP deviation, lagged		-0.04 (0.04)	0.05 (0.05)
LIBOR 1-year	-	0.12*** (0.03)	0.04 (0.04)
Political risks*[1]	-	-	-0.03*** (0.01)
Samples	72	72	60
Adj-R^2	0.41	0.60	0.71
F-statistics	17.73	22.1	25.0

Note: *, **, *** denote sifnificant at 10%, 5%, and 1%, respectively.

*[1]Political risk rating is from annual average of monthly PRC composite risk rating from 1985-2012.

[12]Using a binary variable showing default and non-default choices as one of explanatory variables is an alternative option. We obtain similar results shown in Table 2 with smaller degree of significance. An advantage of our approach is that credit ratings capturing variations of default probability provide better fits.

4 Model environment

Th basic structure of the model is in line witih previous work that exteded sovereign debt model by Eaton and Gersovitz (1981) and applies its quantitative analysis. Among these studies, our paper refers closely to Aguiar and Gopinath (2005) and Arellano (2008). Our incomplete market assumption of capital market under two-country setting follows closely Benigno and Thoenissen (2008) and Chari, Kehoe and McGrattan (2002). A noteworthly feature in our model with respect to these models is that we embed exchange rate determination linked with default choices of the country.

4.1 General points

Our model considers sovereign default and exchange rate fluctuation in a dynamic model of a small open economy. We consider a risk-averse country and a representative risk-averse investor. All information concerning with income processes of two parties and bond issuances are perfect and symmetryc. In each period, the country starts with total debt b_t, a fraction deminated in local currency αb_t and the remaining denominated in foreign currecy $(1-\alpha)b_t$. We provide explanations of fixed share of foreign currency debt in following subsection.

Both the country and the creditor receive stochastic endowment streams of tradable y_t^T, y_t^{T*} and non-tradable y_t^N, y_t^{N*} goods. We denote y_t, a column vector of four income processes: $y_t = \left[y_t^T, y_t^{T*}, y_t^N, y_t^{N*}\right]$. It is stochastic, drawn from a compact set $Y = \left[y_{\min}^T,\ y_{\max}^T\right] \times \left[y_{\min}^{T*},\ y_{\max}^{T*}\right] \times \left[y_{\min}^N,\ y_{\max}^N\right] \times \left[y_{\min}^{N*},\ y_{\max}^{N*}\right] \subset \mathbb{R}_+^4$. $\mu(y_{t+1}|y_t)$ is probability distribution of a shock y_{t+1} conditional on previous realization y_t.

The international capital market is incomplete. The country and foreign investor can borrow and lend only via one-period zero-coupon bonds indexed to its consumer price index (CPI) and there are two types of bonds they issue: bonds denominated in local and foreign currency. b_{t+1} denotes amount of bonds to be repaid next period whose set is shown by $B = [b_{\min},\ b_{\max}] \subset \mathbb{R}$ where $b_{\min} \leq 0 \leq b_{\max}$. The upper bound is the highest level of assets that the country can accumulate and the lower bound is the highest level of debts that the country can hold. We assume $q^i(b_{t+1}, y_t)$ $(i \in \{H, F\})$ be price of bonds with asset position b_t and a vector of y_t. We assume that q^H and q^F are denominated in local and foreign currency respectively. Price functions of both bonds are denominated in equilibrium. WE define the currrent exchange rate e_t as units of local currency against one unit of foreign currency. It is also determined at equilibrium together with bond prices.

We assume that the creditor commits to repay its debt. However the country is free to decide whether to repay its debt or to default. If the country chooses to repay its debt, it will preserve its position to issue bonds continuously next period. If the country chooses not to pay its debt, it is then subject to exclusion from international capital markets and direct output costs. We assume that the country defaults total external debt (b_t). This assumption is supported by an evidence on recent external debt restructurings where sovereigns default on both local and foreign currency debt issued at international markets.

When a default takes place, the country will be temporarily autarkey. After being excluded from the markets for one period, with exogenous probability χ, the country will regain access to the markets. Otherwise, it will remain the same next period.

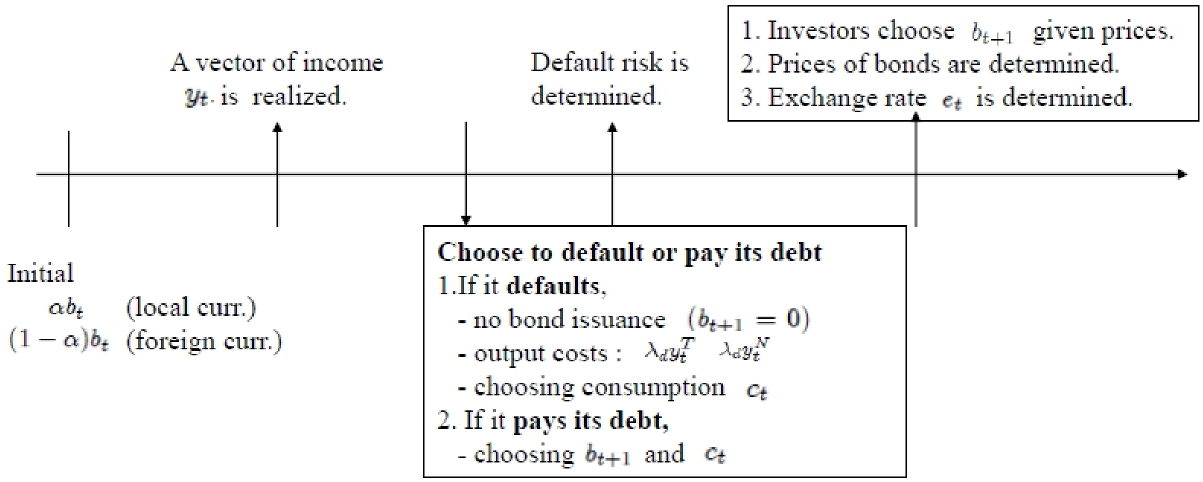
4.2 Timing of the model

Timing of decisions within each period is summarized in Figure 2. The country starts current period with total debt b_t comprised of local and foreign currency debt. After observing a vector of income shocks y_t, the country chooses either to pay its debt or to default.

If the country chooses to pay the total debt, given bond price schedules and current exchange rate, the country chooses next period total debt b_{t+1} and current consumption (c_t). Then default probability is determined. Given bond prices and current exchange rate, the creditor chooses b_{t+1} consistent with brief of default probability. Bond prices together with current exchange rate determined at equilibrium.

On contrary, if the country chooses to default, it suffers direct output costs due to default $\lambda_d y_t^T$, $\lambda_d y_t^N$. The country will be in financial autarky and can not raise funds at internaitonal capital markets this period ($b_{t+1} = 0$). It simply chooses its current consumption. Only current exchange rate (e_t) is determined at equilibrium.

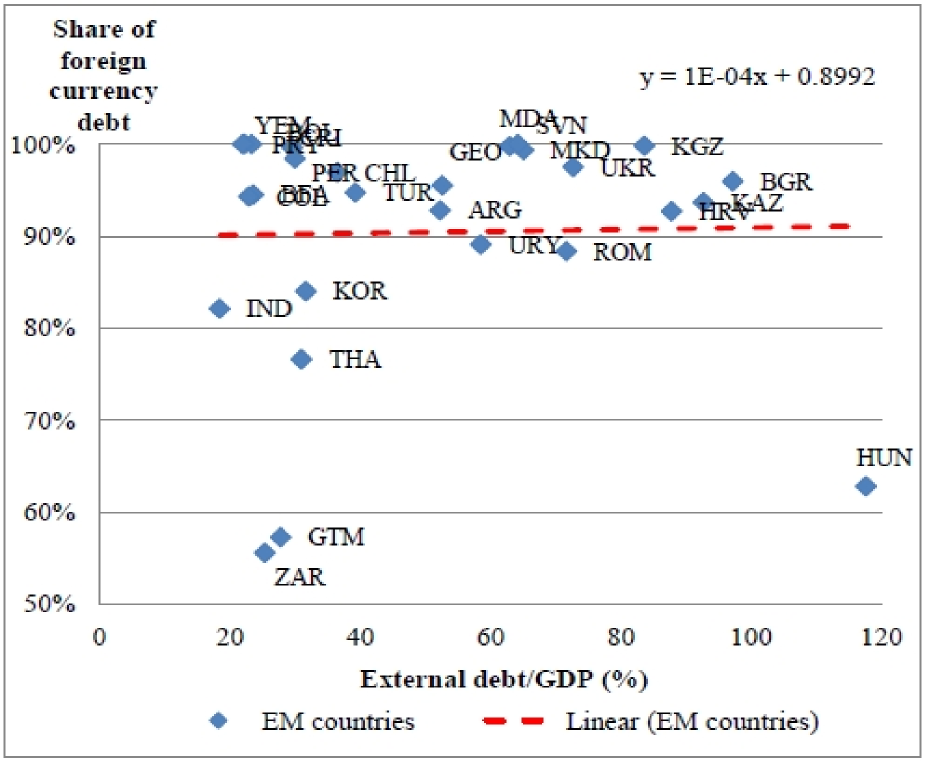
Figure 2: Timing of the Model



4.3 Fixed share of foreign currency-denominated debt

This subsection explains a rationale of assumption on share of foreign currency denominated debt. Most emerging countries tend to have a large fraction of their external debts, more than 90 percent, denominated in foreign currency as shown in Figure 3. What is surprising is that their share of foreign currency denominated debt is independent from the size of external debt (relative to GDP). Panel regression analysis using 28 emerging countries with a sample over 2005-2011 also confirms that share of foreign currency denominated debt is not significantly influenced by neither macroeconomic variables such as external debt-to-GDP ratio, GDP deviation from the trend, exchange rate (entered as percentage change), nor global factors (business cycle, and liquidity) in Table 3. On the contrary, market structural factors (rule of law whether the laws of a country are creditor friendly), investor perceptions (entered as average of discrete forms of credit ratings over last 5 years), category as emerging market countries (shown by constant) affect the share of foreign currency debt shown in Table 3..

Figure 3: Share of foreign currency denominated debt in emerging countries, average in 2005-11



Source: IMF/WB Quarterly External Debt Statistics

Note: 1. According to IMF (2003), gross external debt, at any given time, is the outstanding amount of those actual current, and not contingent, liabilities that require payment(s) of principal and/or interest by the debtor at some point(s) in the future and that are owed to nonresidents by residents of an economy.

2. Data for most countries covers for 2005-11. However, following countries have limited set of data: Solvenia for 2005-7, Bolivia. Bulgalia, India, Kyrgyz Republic, for 2006-11, Kazakhstan for 2006-7, Georgia and Ukraine for 2007-11, Burkina Faso, Guatemala, Yemen, for 2009-10, Romania for 2009-11, Paraguay for 2010, Macedonia for 2011.

Table 3: Panel regression results for share of foreign currency denominated debt

	(A) Baseline	(B) Global factors	(C) Fixed effect
Method	Pooled	Pooled	Fixed effect
Constant	85.8*** (19.1)	81.0*** (21.3)	-
External debt-to-GDP	-0.03 (0.08)	-0.03 (0.08)	0.35 (0.26)
GDP deviation, %	-0.80 (0.62)	-0.69 (0.81)	-0.45 (0.76)
Exchange rate, %-change	-0.07 (0.19)	-0.03 (0.21)	0.02 (0.18)
log (nominal GDP)	-3.07 (1.98)	-3.01 (2.00)	1.83 (12.8)
Rating - foreign curr. bonds*1	-1.87* (1.10)	-1.83 (1.12)	-7.92 (5.24)
Rule of law*2	6.63* (3.80)	6.45 (3.91)	0.39 (9.91)
Past defaults/renegotiations*3	-0.59 (1.50)	-0.55 (1.52)	-
GDP deviation, Adv. econ.	-	-1.26 (2.48)	-
LIBOR 1-year	-	1.68 (3.06)	-
Fixed effect - Argentina	-	-	63.7 (79.4)
Fixed effect - Average	-	-	136.6
Samples	101	101	101
Adj-R^2	0.04	0.02	0.95
F-statistics	1.55	1.22	71.7

Note: *, **, *** denote sifnificant at 10%, 5%, and 1%, respectively.

*1 Rating on foreign currency bonds is average of discrete form of ratings over last 5 years.

*2 For rule of law, we use data from 2005-11 from Gwartney, Lawson and Emerick (2012).

*3 For past defaults and renegotiations, we use data from 1970-2010 from Cruses and Trebesch (2013).

5 Recursive Equilibrium

In this section, we define the stationary recursive equilibrium of the model. Two distinctive feature in our framework are: there are two types of bonds denominated in local and foreign currencies and current exchange rate is endogenously determined at equilibrium satisfying optimality conditions of two parties.

5.1 Sovereign country's problem

The country's problem is to maximize the expected lifetime utility given by

$$E_0 \sum_{t=0}^{\infty} \beta^t u(c_t) \tag{3}$$

where $0 < \beta < 1$ is a discount factor, c_t denotes consumption of borrower in period t, and $u(.)$ is its one-period utility function, which is continuous, strictly increasing and strictly concave and satisfies the Inada conditions. A discount factor reflects both pure time preference and probability that the current sovereignty will survive into next period.

A consumption basket c_t is defined by the CES aggregates of consumption shown as

$$c_t = \left[\omega^{\frac{1}{\kappa}} (c_t^T)^{\frac{\kappa-1}{\kappa}} + (1-\omega)^{\frac{1}{\kappa}} (c_t^N)^{\frac{\kappa-1}{\kappa}}\right]^{\frac{\kappa}{\kappa-1}} \tag{4}$$

where c_t^T and c_t^N are consumptions of tradable and non-tradable goods and κ is the elasticity of intratempral substitutions between these goods. Tradable component is in turn comprised of local and foreign-endowed goods in the following manner:

$$c_t^T = \left[\upsilon^{\frac{1}{\theta}} (c_t^{T,H})^{\frac{\theta-1}{\theta}} + (1-\upsilon)^{\frac{1}{\theta}} (c_t^{T,F})^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}} \tag{5}$$

where we denote with $c_t^{T,H}$ and $c_t^{T,F}$ are consumptions of traded goods endowed in the country and the creditor's country respectively. θ is the elasticity of intratemporal substitution between the country and creditor-endowed traded goods.

Correspoinding to the CES bundles of consumption goods, we have an isomorphic price index:

$$p_t = \left[\omega (p_t^T)^{1-\kappa} + (1-\omega)(p_t^N)^{1-\kappa}\right]^{\frac{1}{1-\kappa}} \tag{6}$$

where p_t^T and p_t^N are prices of traded and non-traded goods. Price of tradable goods is numeraire ($p_t^T = 1$). Tradable good price is in turn comprised of prices of local and foreign-endowed goods:

$$1 = \left[\upsilon (p_t^{T,H})^{1-\theta} + (1-\upsilon)(e_t p_t^{T,F*})^{1-\theta}\right]^{\frac{1}{1-\theta}} \tag{7}$$

where $p_t^{T,H}$ and $p_t^{T,F*}$ are prices of traded goods in each country.

Let $V(b_t, y_t)$ be the life-time value function of the country that starts the current period with initial assets b_t and a vector of income shocks y_t. Given sovereign bond prices $q^i(b_{t+1}, y_t)$ $i = H, F$ and current exchange rate e_t, the country solves its optimization problem.

If the country decides to pay its debt it chooses its next-period asset (b_{t+1}) and its current consumption after paying back its initial debt. On contrary if the country defaults, it will not be able to issue bonds in current period. It simply chooses current consumption.

Given its option to default $V(b_t, y_t)$ satisfies

$$V(b_t, y_t) = \max \left[V^R(b_t, y_t), V^D(y_t) \right] \tag{8}$$

where $V^R(b_t, y_t)$ is its value which the country chooses to pay debt given as

$$V^R(b_t, y_t) = \max_{c_t, b_{t+1}} u(c_t) + \beta \int_Y V(b_{t+1}, y_{t+1}) d\mu(y_{t+1}|y_t) \tag{9}$$

$$s.t. \quad c_t^T + p_t^N c_t^N + p_t \begin{bmatrix} q^H(b_{t+1}, y_t)\alpha + \\ e_t q^F(b_{t+1}, y_t)(1-\alpha) \end{bmatrix} b_{t+1} = p_t^{T,H} y_t^T + p_t^N y_t^N + p_t \left[\alpha + e_t(1-\alpha) \right] b_t$$

and $V^D(y_t)$ is the value which the country decides to default, shown as

$$V^D(y_t) = \max \left\{ u(c_t) + \beta \left[\chi \int_Y V(0, y_{t+1}) d\mu(y_{t+1}|y_t) + (1-\chi) \int_Y V^D(y_{t+1}) d\mu(y_{t+1}|y_t) \right] \right\} \tag{10}$$

$$s.t. \quad c_t^T + p_t^N c_t^N = (1-\lambda_d) p_t^{T,H} y_t^T + (1-\lambda_d) p_t^N y_t^N$$

where $V(0, y_{t+1})$ is its value next period with no initial debt. $p_t^{T,H} y_t^T$ and $\lambda_d p_t^N y_t^N$ express output costs which the country suffers due to a default.When the country decides next-period asset, it also takes into consideration impacts of the current exchange rate which is determined by optimality conditions of the country and its creditor explained in Section 5.3.

The country's default policy can be characterized by default set default set $D(b_t) \subset Y$. It is a set of income vectors y's for which default is optimal given the debt position b_t.

$$D(b_t) = \{y_t \in Y : V^R(b_t, y_t) < V^D(y_t)\} \tag{11}$$

In the case where the country chooses to pay its debt, we obtain the following optimality conditions:

$$\frac{c_t^T}{c_t^N} = \left(\frac{\omega}{1-\omega}\right)\left(\frac{1}{p_t^N}\right)^{-\kappa} \tag{12}$$

$$\frac{c_t^{T,H}}{c_t^{T,F}} = \left(\frac{\upsilon}{1-\upsilon}\right)\left(\frac{p_t^{T,H}}{e_t p_t^{T,F}}\right)^{-\theta} \tag{13}$$

$$\left[q^H(b_{t+1}, y_t)\alpha + e_t q^F(b_{t+1}, y_t)(1-\alpha)\right] = E_t\left[\beta\frac{u'(c_{t+1})}{u'(c_t)}1_{Non-Default}\left[\alpha + e_t(1-\alpha)\right]\right] \tag{14}$$

On contrary, if the country chooses to default, we have equation (12) and (13), not (14).

5.2 Foreign creditor's problem

The foreign creditor is also risk-averse and behaves competitively at the market. The problem is to maximize its expected lifetime utility given by

$$E_0 \sum_{t=0}^{\infty} (\beta^*)^t u(c_t^*) \tag{15}$$

Its consumption basket c_t^* is similar to that of the country:

$$c_t^* = \left[(\omega^*)^{\frac{1}{\kappa}} (c_t^{T*})^{\frac{\kappa-1}{\kappa}} + (1-\omega^*)^{\frac{1}{\kappa}} (c_t^{N*})^{\frac{\kappa-1}{\kappa}}\right]^{\frac{\kappa}{\kappa-1}} \tag{16}$$

where c_t^{T*} and c_t^{N*} are consumptions of traded and non-traded goods. Tradable goods consumtion is composed of consumptions of two tradable goods $c_t^{T*,H}$ and $c_t^{T*,F}$.

$$c_t^{T*} = \left[(\upsilon^*)^{\frac{1}{\theta}} (c_t^{T*,H})^{\frac{\theta-1}{\theta}} + (1-\upsilon^*)^{\frac{1}{\theta}} (c_t^{T*,F})^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}} \tag{17}$$

Correspoinding to the CES bundles of consumption goods, we have an isomorphic price index:

$$p_t^* = \left[(\omega^*)(p_t^{T^*})^{1-\kappa} + (1-\omega^*)(p_t^{N*})^{1-\kappa}\right]^{\frac{1}{1-\kappa}} \tag{18}$$

where p_t^{T*} and p_t^{N*} are prices of traded and non-traded goods. Tradable goods price of creditor is similar to that of the country shown as:

$$p_t^{T*} = \left[(1-\upsilon^*) \left(\frac{p_t^{T,,H}}{e_t} \right)^{1-\theta} + \upsilon^* (p_t^{T,,F})^{1-\theta} \right]^{\frac{1}{1-\theta}} \tag{19}$$

If the country repays its debt, the creditor also decides its assets for next period (b_{t+1}^*) and current consumption c_t subject to its budget constraint such as

$$c_t^{T*} + p_t^{N*} c_t^{N*} + p_t^* \left[\begin{array}{c} \frac{q^H(b_{t+1}, y_t)}{e_t} \alpha \\ + q^F(b_{t+1}, y_t)(1-\alpha) \end{array} \right] b_{t+1}^* = p_t^{T*,F} y_t^{T*} + p_t^{N*} y_t^{N*} + p_t^* \left[\frac{1}{e_t} \alpha + (1-\alpha) \right] b_t^* \tag{20}$$

Then we obtain following optimality conditions:

$$\frac{c_t^{T*}}{c_t^{N*}} = \left(\frac{\omega^*}{1-\omega^*} \right) \left(\frac{p_t^{T*}}{p_t^{N*}} \right)^{-\kappa} \tag{21}$$

$$\frac{c_t^{T*,F}}{c_t^{T*,H}} = \left(\frac{\upsilon^*}{1-\upsilon^*} \right) \left(\frac{p_t^{T,F}}{p_t^{T,H}/e_t} \right)^{-\theta} \tag{22}$$

$$\left[\frac{q^H(b_{t+1}, y_t)}{e_t} \alpha + q^F(b_{t+1}, y_t)(1-\alpha) \right] = E_t \left[\beta^* \frac{u'(c_{t+1}^*)}{u'(c_t^*)} 1_{Non-Default} \left[\frac{1}{e_t} \alpha + (1-\alpha) \right] \right] \tag{23}$$

If the country defaults, the creditor maximizes its utility by choosing currency consumptions subject to its budget constraint:

$$c_t^{T*} + p_t^{N*} c_t^{N*} = p_t^{T*,F} y_t^{T*} + p_t^{N*} y_t^{N*} \tag{24}$$

Then, we have we have equation (21) and (22), not (23).

5.3 Bond prices and exhange rate

Bond price indexed to the sovereign's and creditor's CPI $q^i(b_{t+1}, y_t)$ for $i = H, F$ are functions of next-period asset and a vector of income shocks. It the country chooses to pay its debtm the creditor receives payoffs equal to the face value of bonds, which is normalized to 1. If the country chooses to default, payoffs are zero. We derive bond price functions for both sovereign's and the creditor's Euler equations, which take into account sovereign's decision of paying its debt and defaulting.

$$\left[q^H(b_{t+1}, y_t)\alpha + e_t q^F(b_{t+1}, y_t)(1-\alpha)\right] = E_t\left[\beta \frac{u'(c_{t+1})}{u'(c_t)} 1_{Non-Default}\left[\alpha + e_t(1-\alpha)\right]\right] \tag{25}$$

$$\left[\frac{q^H(b_{t+1}, y_t)}{e_t}\alpha + q^F(b_{t+1}, y_t)(1-\alpha)\right] = E_t\left[\beta^* \frac{u'(c^*_{t+1})}{u'(c^*_t)} 1_{Non-Default}\left[\frac{1}{e_t}\alpha + (1-\alpha)\right]\right] \tag{26}$$

Current exchange rate is defined as relative CPI between the sovereign and the creditors as

$$e_t = \frac{p_t}{p^*_t} \tag{27}$$

5.4 Market clearing conditions for goods and bonds

If the country repays its debt in current period, market clearing conditions for tradable goods and non-tradable goods are

$$c_t^{T,H} + c_t^{T*,H} = y_t^T \tag{28}$$

$$c_t^{T,F} + c_t^{T*,F} = y_t^{T*} \tag{29}$$

$$c_t^N = y_t^N \tag{30}$$

$$c_t^{N*} = y_t^{N*} \tag{31}$$

On contrary, in the case of default, following are market clearing conditions for tradable goods and non-tradable goods endowed in the country.

$$c_t^{T,H} + c_t^{T*,H} = (1-\lambda_d)y_t^T \tag{28'}$$

$$c_t^N = (1-\lambda_d)y_t^N \tag{30'}$$

Market clearing conditions for bonds is

$$\pi b_t + (1-\pi)b^*_t = 0 \tag{32}$$

where π denotes the size of sovereign economy relative to the creditor.

5.5 Recursive equilibrium

We define a stationary equilibrium in the model.

Definition 1 *A Recursive equilibrium is a set functions for (A) the country's value function* $V(b_t, y_t)$*, consumption,* $c(b_t, y_t)$*, asset position* $b_{t+1}(b_t, y_t)$ *and default set* $D^*(b_{t+1})$*, (B) investor's consumption* $c^*(b_t, y_t)$*, asset position* $b^*_{t+1}(b_t, y_t)$*, and (C) bond price function* $q^i(b_{t+1}, y_t)$ *for* $i = H, F$ *and current exchange rate* $e_t(b_{t+1}, y_t)$ *such that*

[1] Given bond prices $q^i(b_{t+1}, y_t)$ *for* $i = H, F$ *and current exchange rate* $e_t(b_{t+1}, y_t)$*, the the country's value function* $V(b_t, y_t)$*, consumption,* $c(b_t, y_t)$*, asset position* $b_{t+1}(b_t, y_t)$ *and default set* $D^*(b_{t+1})$ *satisfy the country's optimization problem.*

[2] Given bond prices $q^i(b_{t+1}, y_t)$ *for* $i = H, F$ *and current exchange rate* $e_t(b_{t+1}, y_t)$*, investor's consumption* $c^*(b_t, y_t)$*, asset position* $b^*_{t+1}(b_t, y_t)$ *, asset position satisfy the investor's optimization problem.*

[3] Bond bond prices $q^i(b_{t+1}, y_t)$ *for* $i = H, F$ *and current exchange rate* $e_t(b_{t+1}, y_t)$ *satisfy optimaility conditions of two parties.*

[4] Market clearing conditions for goods and bonds are satisfied.

In equilibrium, default probability $p(b_{t+1}, y_t)$ is related to sovereign's default decision in the following manner:

$$p(b_{t+1}, y_t) = \int_{D^*(b_{t+1})} d\mu(y_{t+1}|y_t) \tag{33}$$

Risk-free interest rate is defined as

$$\frac{1}{1 + r^*(b_{t+1}, y_t)} = \beta^* E_t \left[\frac{u'(c^*_{t+1})}{u'(c^*_t)} \right] \tag{34}$$

We define total spreads for domestic and foreign currency denominated debt evaluated by creditor's side as follows;

$$s^H(b_{t+1}, y_t) = \frac{e_t}{q^H(b_{t+1}, y_t)} - 1 - r^*(b_{t+1}, y_t) \tag{35}$$

$$s^F(b_{t+1}, y_t) = \frac{1}{q^F(b_{t+1}, y_t)} - 1 - r^*(b_{t+1}, y_t) \tag{36}$$

6 Quantitative Analysis

This section provides quantitative analysis of model. We set parameters and functional forms and discuss equilibrium properties of the model. Simulation results for Argentina are presented in Section 6.3. Similarly, Section 6.4 reports calibration exercises for Russia and Uruguay. Implications for spreads of two bonds are provided in Section 6.5. Finally, we summarize main implications of quantitative analysis.

6.1 Parameters and functional forms,

We use most of parameters and functional forms specified in previous work. There are three new elements in the model associated with two-country, two-goods set-up: (1) relative size of the soverign, (2) weights on consumption of home-endowed tradable goods, and (3) share of domestic currency denominated debt.

The following utility functions are used in numerical simulation:

$$u(c_t) = \frac{c_t^{1-\sigma}}{1-\sigma}, \qquad u(c_t^*) = \frac{c_t^{*1-\sigma}}{1-\sigma} \tag{37}$$

where σ expresses degree of risk aversion. We set σ equal to 2, which is commonly used in real business cycle analysis for emerging markets. The elasticity of substitution between tradable and non-tradable consumption is taken from Gonzales and Neumeyer (2003) where they estimate the elasticity for Argentina to be equal to 0.48. We assume an elasticity of substitution between home and foreign-produced traded goods θ, of 2 as in Benigno and Thoenissen (2008). Weight of tradable goods consumption and home-endowed tradable goods consumptions are set to $\omega = 0.51$, $\omega^* = 0.5$ and $\upsilon = \upsilon^* = 0.5$ in order to have price of tradable goods at steady-state distribution ($p^T = 1$).

The probability of re-entry to credit markets after defaults is set at $\chi = 0.282$, which is consistent with observed evidence regarding the exclusion from credit markets of defaulting countries mentioned in Gelos et al (2011). Output loss parameter λ_d is set to 2% following Sturzeneger (2002)'s estimates. The "representative" creditor's discount factor is set to $\beta^* = 0.98$ as in Lizarazo (2013).[13]

We assume each exogenous endowment stream y_t^i for $i = \{N, T, N^*, T^*\}$ follows a log-normal

[13] Lizarazo (2013) explains the value of $\beta^* = 0.98$ is the highest value in the range commonly used in business cycle analysis of developped countries such that the asset disbution of the creditor is well defined given an international interest rate of 1.7%.

AR(1) process where innovations to the shocks are allowed to be correlated:

$$\log(y_t^i) = \rho_y^i \log(y_{t-1}^i) + \epsilon_y^i \tag{38}$$

where $E[\epsilon_y^i] = 0$ for $i = \{N, T, N^*, T^*\}$ and the variance-covariance matrix of the error terms is the following:

$$E[\epsilon'\epsilon] = \begin{bmatrix} \sigma^T & \sigma^{TN} & \sigma^{TT*} & \sigma^{TN*} \\ \sigma^{TN} & \sigma^N & \sigma^{NT*} & \sigma^{NN*} \\ \sigma^{TT*} & \sigma^{NT*} & \sigma^{T*} & \sigma^{T*N*} \\ \sigma^{TN*} & \sigma^{NN*} & \sigma^{T*N*} & \sigma^{N*} \end{bmatrix} \tag{39}$$

where $\epsilon = [\epsilon_y^T, \epsilon_y^N, \epsilon_y^{T*}, \epsilon_y^{N*}]'$. Auto-regressive processes are estimated using Hodrick-Prescott filtered data on tradable and non-tradable output. The sectoral classification into tradede and non-traded goods follows the traditional approach adopted in real business cycle literature. The sum of "manufacturing" and the primary sectors are categorized as traded goods sector, whereas non-traded goods sector is made up of the sum of remaining sectors. Each shock is then discretized into a finite state Markov chain by using a quadrature procedure in Hussey and Tauchen (1991) from their joint distribution. For creditor's income, using US BEA data from 1988 to 2011, we use estimated coefficients such as $\rho^{N*} = 0.67$, and $\rho^{T*} = 0.49$. For sovereign's income, we find the following estimated coefficients; $\rho^N = 0.70$, and $\rho^T = 0.59$ for Argentina, $\rho^N = 0.54$, and $\rho^T = 0.31$ for Russia, and $\rho^N = 0.70$, and $\rho^T = 0.71$ for Uruguay. Tradable and non-tradable output data is 1988-2007 from MECON (Argentina), 2003-2011 from the State Committee of the Russian Federation (Russia), and 1988-2007 from the Banco Central de Uruguay (Uruguay) respectively.

For remaining country specific parameters, size of sovereign relative to that of creditor is set to 0.025 (Argentina), 0.057 (Russia), and 0.002 (Uruguay) respectively to reflect ratio of US dollar GDP of sovereigns relative to that of the US over the period 1993-2012. Sturzenegger and Zettlemeyer (2006) report that Argentina, Russia and Uruguay experienced 6, 3 and 6 defaults in 1820-2004. We specify the sovereign's discount factor $\beta = 0.82$ (Argentina), $\beta = 0.89$ (Russia), $\beta = 0.95$ (Uruguay) to obtain their average default frequency 3.26% (Argentina), 1.63% (Russia) and 3.26% (Uruguay). Share of domestic currency denominated debt is set at 0.07 (Argentina), 0.05 (Russia), and 0.11 (Uruguay) based on avearage share over period 2005-11 from the IMF WB Quaterly External Debt

Statistics (Argentina and Uruguay) and Bloomberg (Russia).[14]

Table 4: Model Parameters

Parameter	Value			Sources
General				
Risk aversion	$\sigma = 2$			RBC literature
Elast. of sub. b/w c^T, c^{T*}	$\kappa = 0.48$			Gonzales and Neumeyer (2003)
Elast. of sub. b/w $c^{T,H}$, $c^{T*,F}$	$\theta = 2$			Benign and Thoenissen (2008)
Weight of c^T, c^{T*} in CES	$\omega = 0.51$, $\omega^* = 0.50$			Computed
Weight of $c^{T,H}$, $c^{T*,F}$ in CES	$\upsilon = \upsilon^* = 0.5$			Computed
Probability of reentry	$\chi = 0.282$			Gelos et al (2011)
Output cost	$\lambda_d = 0.02$			Sturzenegger (2002)
Discount rate - Creditor	$\beta^* = 0.98$			Lizarazo (2013)
Autoreg. of income - creditor	$\rho^{N*} = 0.67$, $\rho^{T*} = 0.49$			Computed - US BEA
Country-specific	(i) ARG	(ii) RUS	(iii) URG	
Autoreg. of income - country	$\rho^N = 0.70$,	$\rho^N = 0.54$	$\rho^N = 0.70$	Computed - MECON,
	$\rho^T = 0.59$	$\rho^T = 0.31$	$\rho^T = 0.71$	SCRF (Russia), CBU
Relative size of sovereign	$\pi = 0.025$	$\pi = 0.057$	$\pi = 0.002$	IMF WEO
Discount rate	$\beta = 0.84$	$\beta = 0.85$	$\beta = 0.95$	Computed
Share of dome. curre. debt	$\alpha = 0.07$	$\alpha = 0.05$	$\alpha = 0.11$	IMF WB QEDS/Bloomberg

Note: Varince-covariance matrices of the error terms are reported in Appendix B.

6.2 Numerical results on equilibrium properties

In this subsection, we cover the equilibrium properties of model. Figure 4 shows that default probability at mean level of traded goods is weakly increasing with respect to level of total debt. Furthermore, default probability is weakly increasing respect to level of traded goods. These two findings are consistent with recent quantitative analysis of sovereign debt as in Aguiar and Gopinath (2006), Arellano (2008) and Yue (2010) that the sovereign is more prone to default when it has accumulated its debt and a bad income shock.

[14] For Russia, since we do not have any data available in IMF WB Quarterly Debt Statistics, we compute the share of domestic currency-denominated debt based on bond instruments issued after its debt restructuring in August 2000 available from Bloomberg.

Figure 4: Default Probability

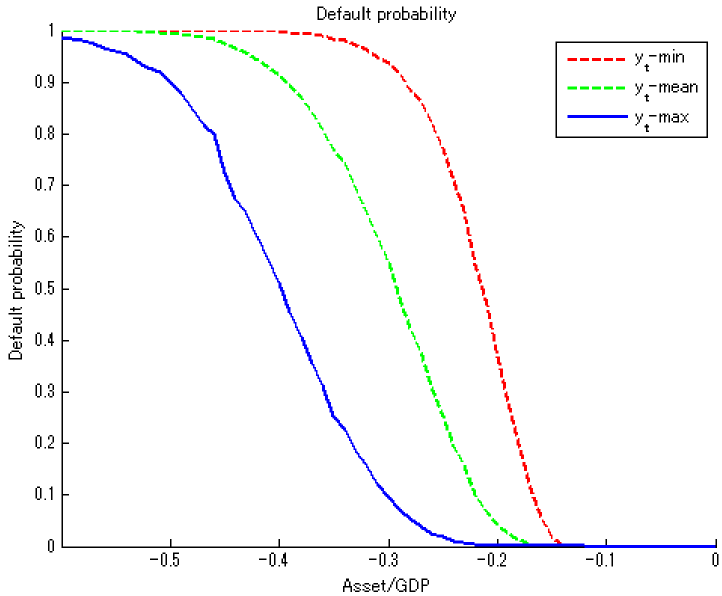


Figure 5: Exchange Rates

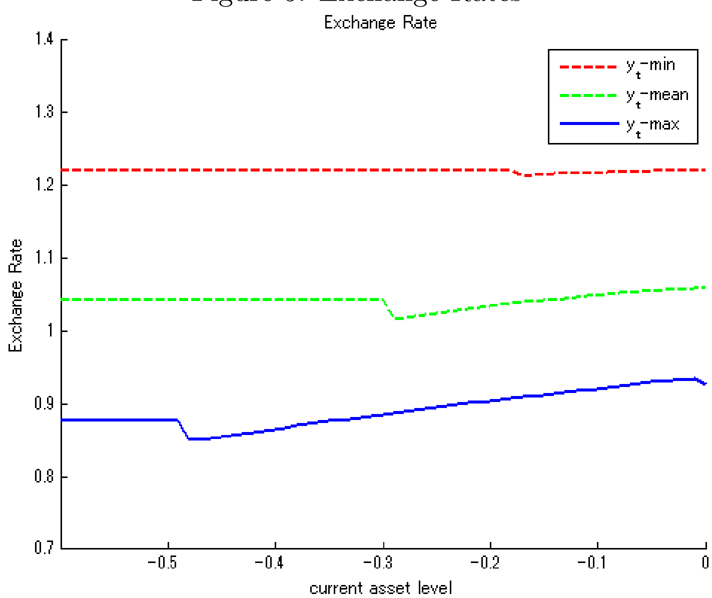


Figure 5 displays that at given level of traded goods, below threshold of debt/GDP ratio where the sovereign opts to default, low level of exchange rate meaning appreciation is associated with high current debt/GDP ratio. With fixed traded good income shock, higher current debt leads to lower consumption of traded goods indicating higher marginal utility of consumption. This in turn results in both lower price of traded goods and lower overall price. On the contrary, when the sovereign defaults at current debt, exchange rate tends to depreciate By defaulting, the sovereign prefers to have higher consumption of traded goods indicating lower marginal utility of consumption which leads to both higher price of non-traded goods and higher overall price level.

Moreover, level of the exchange rate is high implying depreciation when the sovereign has low level of traded goods. With low level of traded goods, the sovereign tends to accumulate higher debt which leads to increase in default probability. Then the exchange rate depreciates associated with increase in default probability. Price functions for newly issued debt and debt level are shown in Appendix C.

6.3 Simulation - Argentina

We conduct 1000 rounds of simulations, with 2000 periods per round, and then extract the last 200 periods to analyze features evaluated at the steady-state distribution. In the last 200 periods, we choose 40 observations before and after a default event to compare to moments in data for Argentina. The second column in Table 5 and 6 summarizes moments in data.[15] Output data are seasonally adjusted from the MECON for 1993Q1-2001Q4 and 2002Q1-2011Q4. Trade balance is calculated as ratio to GDP. Argentina's external debt data are from the IMF WEO for 1993-2001 and 2002-2011. We calculate two measures of the sovereign's indebtness; the first measure is the average external debt/GDP ratio. We also compute the ratio of the country's debt service (including short-term debt) to its GDP for Argentina. Bond spreads are from the J.P. Morgan's Emerging Market Bond Index Global (EMBIG) for Argentina for 1997Q1-2001Q4 and 2002Q1-2011Q4. Real exchange rate are computed based on monthly Argentina nominal exchange rate against the US dollar, Argentina CPI, and US CPI from IMF IFS for 1993Q1-2001Q4 and 2002Q1-2011Q4. We compare our simulation results with those of Arellano (2008) and Aguiar and Gopinath (2006).

As obvious from Table 5, the model matches business cycle statistics in data in both pre-default and post-default periods. Our model replicates volatile consumption and trade balance/GDP volatility, both of which are prominent features of emerging economy business cycle models. Moreover, it also generates a negative correlation between trade balance and output.

Table 5: Business Cycle Statistic

[15] See also Arellano (2008) and Yue (2010) for similar treatment of simulation.

	Data	Model	A and G (2006)	Arellano (2008)
Before Default				
Consumption Std/Output Std	1.11	6.01	1.06	1.10
Trade balance/Output Std. Dev. (%)	0.36	0.09	0.21	0.26
Corr. (Trade Balance/GDP, Output)	-0.87	-0.07	-0.18	-0.25
After Default				
Consumption Std/Output Std	1.15	3.23	-	-
Trade balance/Output Std. Dev. (%)	0.40	0.08	-	-
Corr. (Trade Balance/GDP, Output)	-0.93	-0.06	-	-

Source: Aguiar and Gopinath (2006) and Arellano (2008), MECON

On non-business cycle statistics, the model shows relations among bond spreads, debt/GDP ratio and output as in the data in both pre-default and post-default periods. Bond spreads are possitively correlated with debt/GDP ratio, but negatively correlated with output. This is because default probability is high leading to higher spreads when debt/GDP ratio is high and output is low. Our simulation also reproduces similar levels of average bonds spreads and spreads volatility in both pre-default and post-default periods, though simulated moments in post-default periods are closer to data. However, we see some deviations of average debt/GDP ratio from the total debt service/GDP ratio in data in both pre-default and post-default periods.

What makes our model unique compared to previous studies is that current simulation exercise accounts for new four statistics of exchange rate. Among four moments, it is noteworthy that cuurent model replicates higher average exchange rate in post-default period than in pre-default periods as observed in data. We also explain that exchange rate negatively correlates with output, but positively correlates with spreads in both pre-default and post-default periods. Simulated exchange rate volatility is 9.6%, close to data (5.0%) in pre-default period, whereas it is 9.4% much lower than data (27.6%) in post-default period.

Table 6: Model statistics for Argentina (in quarterly frequency)[1]

	Data	Model	A and G (2006)	Arellano (2008)
Target Statistics				
Default Probability	3.26	3.22	0.92	3.00
Non-target Stastics				
Before Default				
Average Debt/GDP ratio	45.4 / 8.0	15.0	-	5.95
Corr. (Spreads, Output)[2]	-0.88	-0.05	-0.288	-0.29
Average Bond Spreads[2]	9.4	5.7		3.58
Bond Spreads Std. Deviations (%)[2]	7.6	5.4	8.00	6.38
Corr. (Debt/GDP, Spreads)[2]	0.92 / 0.93	0.12		-
Average Exchange Rate	0.89	1.01		-
Exchange rate Std. Deviations (%)	5.0	9.6		-
Corr. (Exchange, Output)	-0.88	-0.04		
Corr. (Exchange, Spreads)[2]	0.58	0.84		
After Default				
Average Debt/GDP ratio	75.3 / 19.8	12.7		-
Corr. (Spreads, Output)	-0.73	-0.06		-
Average Bond Spreads	6.7 / 22.9	5.9		-
Bond spreads Std. Deviations	4.0 / 23.1	5.5		-
Corr. (Debt/GDP, spreads)	0.95 / 0.83	0.31		-
Average Exchange Rate	2.01 / 1.06	1.03		-
Exchange rate Std. Deviations (%)	27.6	9.4		-
Corr. (Exchange, Output)	-0.73	-0.04		
Corr. (Exchange, Spreads)	0.69	0.81		

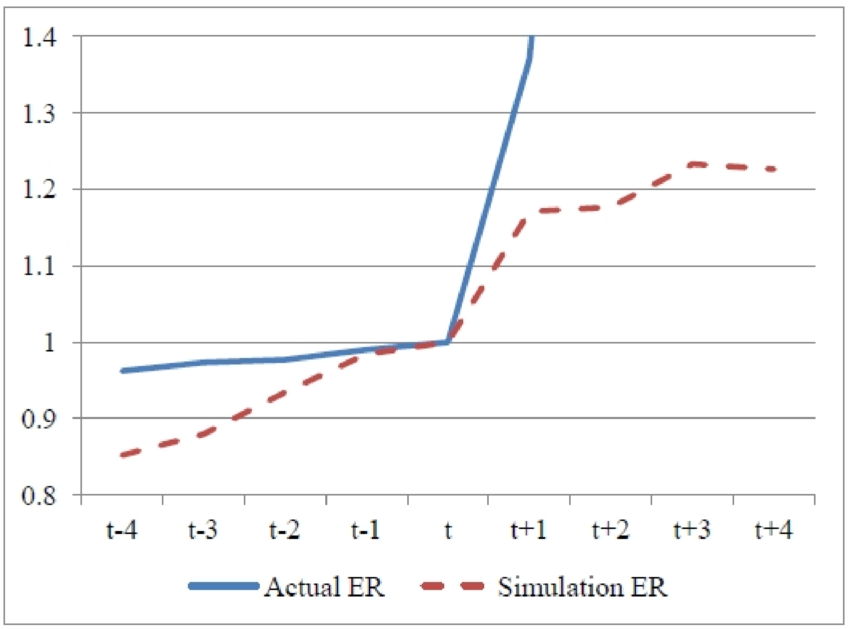
Source: Aguiar and Gopinath (2006), Arellano (2008), Datastream, IMF IFS and WEO, MECON

[1] Spreads corresponds to spreads on foreign currency denominated bonds.

[2] Data for spreads is from 1997Q1 to 2001Q4 for Argentina.

Figure 6 contrasts the simulated process with the actual dynamics of the exchange rate of Argentina before and after default. We replicate two features of exchange rate movements around default. In the model, before default, the sovereign receiving a series of bad traded goods income shocks, tends to accumulate more debt and faces exchange rate depreciation. Since a majority of debt is denominated in foreign currency, this in turn, increases the burden of payments in terms of local currency increasing default probability and forcing the sovereign to default. Once the sovereign declares default, it suffers output costs due to default and loses access to the market. By defaulting, the sovereign enjoys higher consumption of traded goods indicating lower marginal utility of consumption which leads to both higher price of non-traded goods and higher overall price level. Thus, it ends up with a further depreciation of exchange rate. This mechanism drives the equilibrium depreciation of exchange rate in the model and it is a plausible explanation of observed pattern in the data.

Figure 6: Exchange Rates Dynamics



Source: Author's computation and IMF IFS

6.4 Simulation - Russia and Uruguay

We take the same approach of simulation and complete exercises for Russia and Uruguay.[16] Moments in data are summarized in the second and fourth columns in Table 7 and 8. Output data are seasonally adjusted from the SCRF (Russia) for 1993Q1-1998Q3 and 1998Q4-2011Q4, and from the CBU (Uruguay) for 1997Q1-2003Q1 and 2003Q2-2011Q4. Once again, trade balance is computed as ratio to GDP. External debt data are from the IMF WEO for 1993-1998 and 1999-2011 for Russia, and

[16]For Russia, we extract the last 400 periods of 2000 periods per round since default events are less likely to occur.

1993-2002 and 2003-2011 for Uruguay. Bond spreads are from the J.P. Morgan's Emerging Market Bond Index Global (EMBIG) for 1998Q1-1998Q3 and 1998Q4-2011Q4 (Russia) and for 2001Q2-2003Q1 and 2003Q1-2011Q4 (Uruguay). Real exchange rates are computed based on monthly Russian and Uruguayan nominal exchange rate against the US dollar, Russian and Uruguayan CPI, and US CPI from IMF IFS for 1995Q1-1998Q3 and 1998Q4-2011Q4 (Russia) and 1993Q1-2003Q1 and 2003Q2-2011Q4 (Uruguay).

First, on business cylcle statistics, our calibration exercises for Russia and Uruguay reproduce volatile consumption and trade balance/GDP volatility in both pre-default and post-default periods. On relation between trade balance and output, however, the model does not show neither a positive correlation in Russia nor a negative correlation in Uruguay in both pre-default and post-default periods.

Table 7: Business Cycle Statistics

	Russia		Uruguay	
	Data	Model	Data[1]	Model
Before Default				
Consumption Std/Output Std	1.01	3.68	1.09	2.95
Trade balance/Output Std. Dev. (%)	0.11	0.09	0.39	0.09
Corr. (Trade Balance/GDP, Output)	0.31	-0.57	-0.89	0.20
After Default				
Consumption Std/Output Std	0.51	1.89	1.08	1.15
Trade balance/Output Std. Dev. (%)	0.48	0.09	0.32	0.08
Corr. (Trade Balance/GDP, Output)	0.21	-0.55	-0.75	0.20

Source: Banco Central de Uruguay, and State Committee of the Russian Federation

[1]Annual data.from 1993 to 2007.

Next, on non-business cycle statistics, in the case of Uruguay, bond spreads are possitively correlated with debt/GDP ratio and negatively correlated with output in both pre-default and post-default periods as seen in data. On the contrary, Russian calibration result only explains a possitive correlation between bond spreads and debt/GDP ratio in both pre-default and post-default periods. Our simulation partially replicates moments of average bond spreads and spreads volatility as in data: both post-default periods in the case of Russia and pre-default periods in the case of Uruguay. Though we have some sizable deviations of average debt/GDP ratio from total debt service/GDP ratio in data in pre-default period, estimated moments in post-default periods are close to data.

On exchange rate statistics, our calibrations for both Russia and Uruguay again generate higher average exchange rate in post-default periods than in pre-default periods as observed in data. In Uruguayan case, we show that exchange rate correlates negatively with output and positively with spreads in both pre-default and post-default periods. However, in Russian case, the model only replicates the latter: a positive correlation between spreads and exchange rate. Estimated exchange rate volatility is closer to data in pre-default and post-default periods.

Table 8: Model statistics for Russia and Uruguay (in quarterly frequency)[1]

	Russia		Uruguay	
	Data	Model	Data	Model
Target Statistics				
Default Probability	1.63	1.66	3.26	3.30
Non-target Stastics				
Before Default				
Average Debt/GDP ratio	60.1 / 5.8	13.4	59.1 / 13.1	4.8
Corr. (Spreads, Output)[2]	-0.94	0.33	-0.73	-0.29
Average Bond Spreads[2]	17.8	5.9	7.7	6.8
Bond Spreads Std. Deviations (%)[2]	17.6	5.9	5.1	6.9
Corr. (Debt/GDP, Spreads)[2]	n.a. / n.a.	0.27	1.0 / 1.0	0.25
Average Exchange Rate	0.89	1.02	0.57	1.03
Exchange Rate Std. Deviations (%)	16.5	10.5	13.3	8.8
Corr. (Exchange, Output)	0.32	0.44	-0.55	-0.33
Corr. (Exchange, Spreads)[2]	1.00	0.83	0.99	0.87
After Default				
Average Debt/GDP ratio	42.5 / 13.7	11.6	15.3 / 10.5	3.5
Corr. (Spreads, Output)	-0.31	0.31	-0.33	-0.29
Average Bond Spreads	4.7	6.0	3.7	7.3
Bond Spreads Std. Deviations	11.2	5.9	1.9	7.1
Corr. (Debt/GDP, Spreads)	0.85 / 0.75	0.25	0.83 / 0.61	0.23
Average Exchange Rate	0.94	1.03	0.67	1.05
Exchange Rate Std. Deviations (%)	33.2	10.3	16.1	9.7
Corr. (Exchange, Output)	-0.08	0.44	-0.27	-0.33
Corr. (Exchange, Spreads)	0.70	0.81	0.69	0.88

Source: Banco Central de Uruguay, Datastream, IMF IFS and WEO, State Committee of the Russian Federation

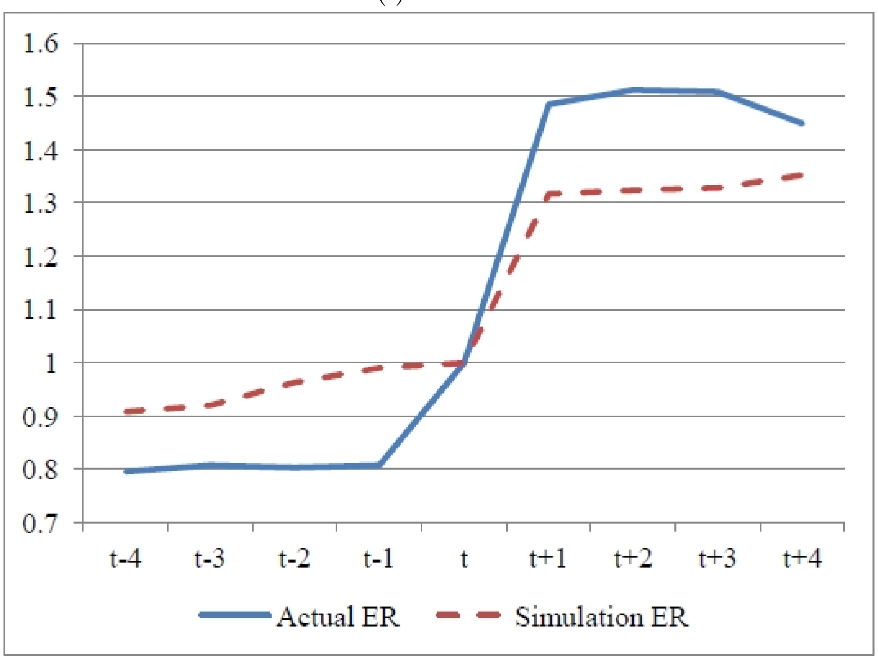
[1] Spreads correspond to spreads on foreign currency denominated bonds.

[2] Data for spreads is from 1998Q1 to 1998Q3 for Russia and from 2001Q1 to 2002Q4 for Uruguay.

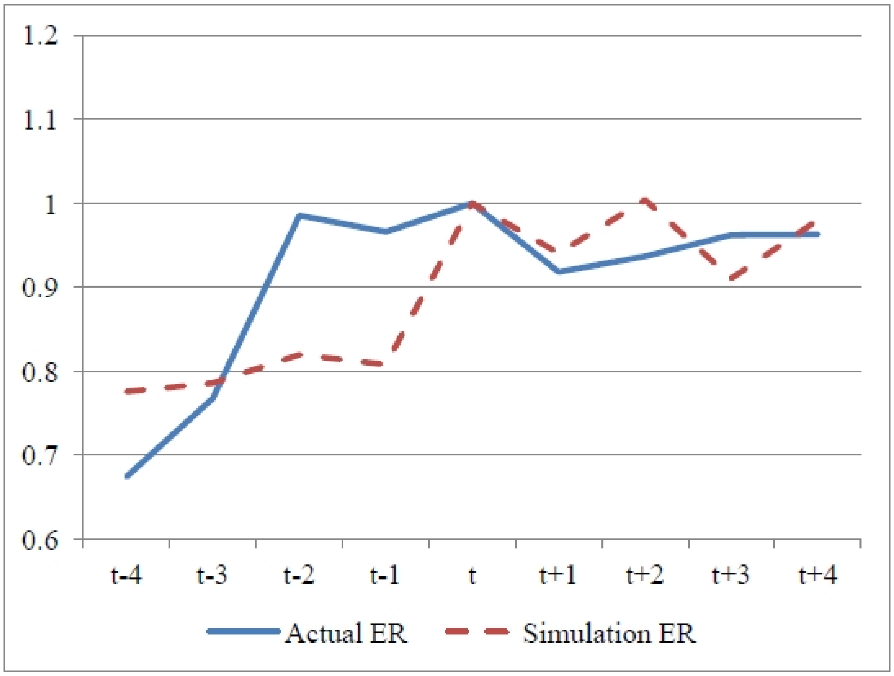
Figure 7 shows charts for Russia and Uruguay comparing the simulated process with the actual series of the exchange rate before and after default. In Russian case, the model generates two prominent characteristics of the exchange rate movements around default. As explained in Section 6.3, in pre-default periods, a combination of both exchange rate depreciation originated by low traded goods income shocks and a large share of foreign currency denominated debt triggers the sovereign's default choice. After default, exchange rate in turn, depreciates further due to output cost of defaulting and loss in market access. In Uruguay case, the model also reproduces observed pattern of exchange rate dynamics: both sharp depreciations before default and fluctuations around the level of exchange rate at default in post-default periods.

Figure 7: Exchange Rates Dynamics

(i) Russia



(ii) Uruguay



Source: Author's computation and IMF IFS

6.5 Spreads on domestic and foreign currency bonds

In this subsection, we compare simulated moments of spreads on domestic and foreign currency denominated bonds in pre-default and post-default periods with data.[17] For both cases of Argentina and Russia, current model replicates a common feature that spreads on domestic currency bonds are higher than those of foreign currency bonds incorporating exchange rates. While we match well average bond spreads for foreign currency bonds in both Argentine and Russian cases, we see some deviations of simulated spreads on domestic currency bonds from data.

For bond spreads standard deviations, though our model accounts for foreign currency bonds in Argentine case, estimated moments deviate slightly from the data for the rest. .

Table 9: Statistics for Bond Spreads

[17] Lack of spreads data on domestic currency bonds before 2009M1, we focus on moments of spreads in post-default periods. In addition, domestic bond data for Uruguay is not available.

	Argentina		Russia	
After default	Data[1]	Model	Data[2]	Model
Domestic currency debt				
Average Bond Spreads	26.4	16.4	8.0	16.0
Bond Spreads Std. Dev.(%)	15.7	5.1	1.9	5.8
Foreign currency debt				
Average Bond Spreads	6.7 / 22.9	5.9	4.7	6.0
Bond Spreads Std. Dev.(%)	4.0 / 23.1	5.5	11.2	6.0

Sources: Author's computation and Bloomberg

[1] For domestic currency denominated debt, data is from 2009M1 to 2011M5.

[2] For domestic currency denominated debt, data is from 2009M1 to 2011M11.

6.6 Brief summary of quantitative analysis

Our major findings can be summarized as follows. First of all, at the steady state distribution, we show that at any level of traded goods, exchange rate tends to depreciate sharply when the sovereign defaults. Second, we find that level of exchange rate is high, i,e, depreciated when the sovereign has low traded goods income shock. Third, our simulation exercises using Argentine, Russian and Uruguayan data replicates that our model accounts both business cycle and non-business cycle regularities including moments of exchange rates in both pre-default and post-default periods. Lastly, most importantly, we explain the link between exchange rate dynamics and default choices (default probability) before and after default.

7 Model implications

In this section, we explore determinants of exchange rate dynamics. As aforementioned, the most important parameters are those governing the income processes and share of foreign currency denominated debt. Hense, we first report the effects of income processes on default probability and exchange rate moments. We then examine influence of share of foreign currency denominated debt.

7.1 Income fluctuations and exchange rate dynamics

Table 10 reports default probability and exchange rate moments under different values of autocorrelation coefficients ρ^T, ρ^N, and the standard deviation of endowments σ^T, σ^N leaving other parameters at their benchmark values.

Higher autocorrelations of income processes for both traded goods and non-traded goods imply more persistent endowment shocks, hence leading to higher default probability. As bond speads reflect expected default probability and are highly correlated with exchange rate, these also result in high standard deviations of exchange rate in both pre-default and post-default periods. While high autocorrelation of traded goods income process amplifies degree of negative correlation between exchange rate and output, high autocorrelation of non-traded goods income process increases the positive correlation. This is because more persistant traded goods shocks lead to high price of non-traded goods due to frequent defaults, and exchange rate depreciation. On the contrary, more persistant non-traded goods result in low price of non-traded goods and low exchange rate.

Volatile income processes for both traded and non-traded goods are linked with higher default probability. As explained above, through positive correlation between exchange rate and spreads, these relate to high standard deciations of exchange rate in both pre-default and post-default periods. In addition, volatile processes of both traded goods and non-traded goods amplify degree of correlation between exchange ratea and output.

Table 10: Model statistics for Argentina (in quarterly frequency)

	Baseline	ρ^T		ρ^N		σ^T		σ^N	
		0.3	0.8	0.4	0.9	0.02	0.058	0.02	0.058
Default probability (%)	3.22	2.71	4.27	2.49	4.69	1.83	3.61	1.98	4.36
Before Default									
Average Exchange Rate	1.01	1.01	1.01	1.01	1.01	1.00	1.01	1.01	1.02
Exchange Rate Std. Dev. (%)	9.6	9.4	9.6	9.3	9.7	7.7	10.0	10.3	10.3
Corr. (Exchange, Output)	-0.04	0.30	-0.25	-0.39	0.12	0.60	-0.13	-0.59	0.2
Corr. (Exchange, Spreads)	0.84	0.83	0.85	0.84	0.83	0.83	0.84	0.87	0.83
After Default									
Average Exchange Rate	1.03	1.02	1.03	1.02	1.03	1.02	1.03	1.02	1.03
Exchange Rate Std. Dev (%)	9.4	9.1	9.5	9.1	9.4	7.5	9.8	8.1	10.3
Corr. (Exchange, Output)	-0.04	0.30	-0.25	-0.36	0.11	0.59	-0.13	0.58	0.19
Corr. (Exchange, Spreads)	0.81	0.82	0.80	0.83	0.79	0.85	0.80	0.84	0.79

Source: Author's calculation

7.2 Share of foreign currency denominated bonds and exchange rate

Table 11 shows how default probability and exchange rate moments change under different values of share of foreign currency denominated debt α leaving other parameters at their benchmark values. High share of foreign currency denominated debt lead to higher default probability and higher average exchange rate in both pre-default and post-default periods; if the sovereign is highly exposed to foreign currency denominated debt, exchange rate depreciation sharply increases burden of payments in terms of local currency increasing default probability. On the contrary, standard deviations of exchange rate are smaller mostly due to high average exchange rate when share of foreign currency denominated debt is high.

Table 11: Model statistics for Argentina (in quarterly frequency)

	Share of foreign currency denominated debt			
	$\alpha = 0.44$	$\alpha = 0.5$	$\alpha = 0.9$	$\alpha = 1.0$
Default probability (%)	2.99	3.02	3.22	3.31
Before Default				
Average Exchange Rate	1.00	1.00	1.01	1.01
Exchange Rate Std. Dev. (%)	10.0	10.0	9.6	9.5
Corr. (Exchange, Output)	-0.05	-0.05	-0.04	-0.04
Corr. (Exchange, Spreads)	0.84	0.82	0.84	0.84
After Default				
Average Exchange Rate	1.01	1.02	1.03	1.03
Exchange Rate Std. Dev (%)	9.8	9.7	9.4	9.4
Corr. (Exchange, Output)	-0.05	-0.06	-0.04	-0.05
Corr. (Exchange, Spreads)	0.83	0.79	0.81	0.81

Source: Author's calculation

8 Conclusion

Emerging countries experience exchange rate depreciations around the default events. This paper attempts to explore this observed evidence within a dynamic stochastic general equilibrium model in which bond issuance in local and foreign currencies are explicitly embedded and exchange rate and default risk are determined endogenously. Our quantitative analysis using data of Argentina, Russia and Uruguay replicates link between exchange rate depreciation and default probability before and after defaults.

In the model, before default, the sovereign receiving a series of bad traded goods income shocks, tends to accumulate more debt and faces exchange rate depreciation. Since a majority of debt is denominated in foreign currency, this in turn, increases the burden of payments in terms of local currency increasing default probability and forcing the sovereign to default. Once the sovereign declares default, it suffers output costs due to default and loses access to the market. By defaulting, the sovereign perfers to have higher consumption of traded goods indicating lower marginal utility of consumption which leads to both higher price of non-traded goods and higher overall price level.

Thus, it ends up with a further depreciation of exchange rate. This mechanism drives the equilibrium depreciation of exchange rate in the model and it is a plausible explanation of observed pattern in the data. Hence, the model is able to replicate the stylized facts of exchange rate and defaults.

So far, we have analyzed the endogenous exchange rate dynamics before and after the default in the framework where income processes are exogenous and output cost is fixed. It will be possible to consider interactions between exchange rate depreciation and output costs due to default as in Mendoza and Yue (2012). This might be potential area where the future research could explore next.

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A Computation Algorithm

The procedure to compute the stationary equilibrium distribution of the model is the following: We compute the limit of finite-horizon problem. We start with the period with the last period.

(i) First, we set grids on the space of asset holdings as $B = [-0.6, ..., 0]$. The limits of the asset space are set to ensure that the limits do not bind in equilibrium.

(ii) Second, we set finite grids on the space of endowments of both sovereign and creditor. The limits of each endowment space are big enough to include large deviations from average value of shocks. We approximate stochastic income processes given by equation (38) using a discrete Markov chain of equally spaced grids. Moreover, we calculate the transition matrix based on the probability distribution $\mu(y_{t+1}|y_t)$.

(iii) Third, we set the initial value of exchange rate ($e_0 = 1$, and $e_0^D = 1$).

(iv) Fourth, we set the initial value for equilibrium bond price We use the risk-free bond price ($q_1 = \bar{q} = (1+r)^{-1}$) for the baseline value for equilibrium bond price.

(v) Fifth, given the baseline equilibrium bond price ($q_0^H = \bar{q}$) and exchange rate ($e_0 = 1$), we solve for the country's and its creditor's optimization problems. This procedure finds the value function as well as default decisions. In order to solve the limit of finite-horizon problem, we solve in backwards.

We start with the problem of last period. Then we solve the last two-period problem. We keep iterating the process until we obtain the converged value function.

We first guess the value function (V^0, $V^{D,0}$) and iterate it using the Bellman equation to find the fixed value (V^*, $V^{D,*}$), given the baseline bond price and exchange rate. By iterating the Bellman function, we also derive the optimal asset policy function (b'). In addition, we also obtain default choices, which require comparison of values of defaulting and non-defaulting. By contrasting these two values, we calculate a default set. Based on derived default set, we also evaluate the default probability using a transition matrix.

(vi) Sixth, using a default set in step (v) and bond price equations (25) and (26), we compute the new bond price (q_1^H and q_1^F). Then we iterate (v) to have a fixed value of the equilibrium bond price.

(vii), Seventh, using the default set in step (v) and equation (12), (13), (21), (22) and (27), we calculate the new exchange rate (e_1, e_1^D). Then we iterate step (v) and (vi) to have a fixed value of equilibrium exchange rate.

B Parameters for calibrations

and the variance-covariance matrix of the error terms is the following:

$$E[\epsilon'\epsilon] = \begin{bmatrix} \sigma^{T} & \sigma^{TN} & \sigma^{TT*} & \sigma^{TN*} \\ \sigma^{TN} & \sigma^{N} & \sigma^{NT*} & \sigma^{NN*} \\ \sigma^{TT*} & \sigma^{NT*} & \sigma^{T*} & \sigma^{T*N*} \\ \sigma^{TN*} & \sigma^{NN*} & \sigma^{T*N*} & \sigma^{N*} \end{bmatrix}$$

where $\epsilon = [\epsilon_y^T, \epsilon_y^N, \epsilon_y^{T*}, \epsilon_y^{N*}]'$.

(i) Argentina

$$E[\epsilon'\epsilon] = \begin{bmatrix} 0.0027 & 0.0019 & 0.0002 & 0.0004 \\ 0.0019 & 0.0019 & 0.0003 & 0.0006 \\ 0.0006 & 0.0002 & 0.0006 & 0.0002 \\ 0.0003 & 0.0002 & 0.0002 & 0.0002 \end{bmatrix} \tag{A1}$$

(ii) Russia

$$E[\epsilon'\epsilon] = \begin{bmatrix} 0.0027 & 0.0064 & 0.0016 & 0.0009 \\ 0.0064 & 0.0041 & 0.0001 & 0.0001 \\ 0.0016 & 0.0001 & 0.0006 & 0.0002 \\ 0.0069 & 0.0001 & 0.0002 & 0.0002 \end{bmatrix} \tag{A2}$$

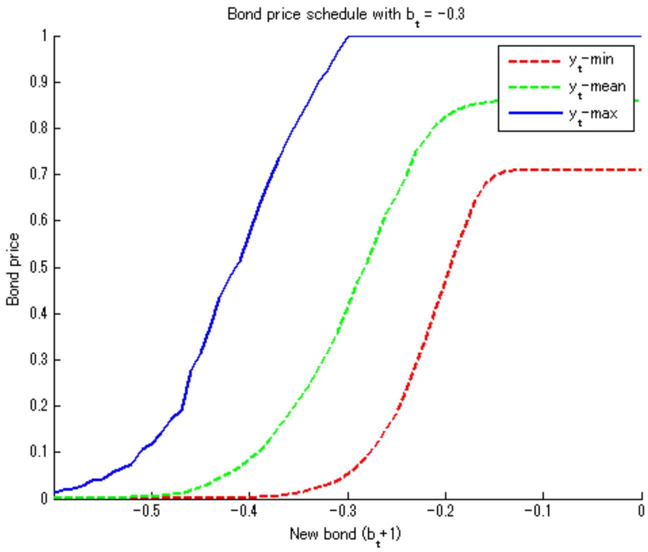
(iii) Uruguay

$$E[\epsilon'\epsilon] = \begin{bmatrix} 0.0040 & 0.0033 & 0.0008 & 0.0003 \\ 0.0033 & 0.0018 & 0.0006 & 0.0002 \\ 0.0008 & 0.0006 & 0.0006 & 0.0002 \\ 0.0003 & 0.0002 & 0.0002 & 0.0002 \end{bmatrix} \tag{A3}$$

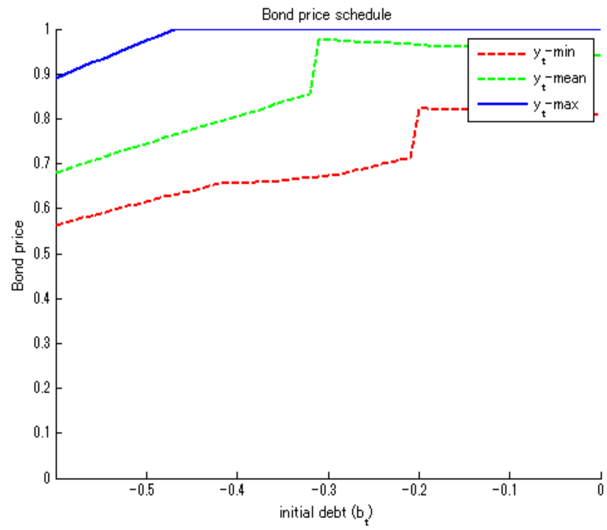
C Figures for bond price function

Left panel of Figure A1 shows the bond price schedule with different level of new debt issuance given initial debt of 0.3. It is prominent that bond price is weakly decreasing with level of new bond issuance since it incorporates default probability which is weakly increasing with respect to level of new bond issuance. Next, bond price schedule with initial level of debt is presented in right panel of Figure A1. At each level of debt, it is computed based on optimal amount of bond issuance. This figure clearly shows that bond price is weakly decreasing with level of initial debt because expected default probability is higher for high level of initial debt.

Figure A1: Bond Price



Bond price schedule with b_t = −0.3
Bond price
New bond (b_t+1)
y_t−min
y_t−mean
y_t−max



Bond price schedule
Bond price
initial debt (b_t)
y_t−min
y_t−mean
y_t−max