International Reserves and Central Bank Independence*

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Abstract

Motivated by a positive correlation between reserve accumulation and the widespread adoption of central bank independence legislation in Latin America, this paper develops a sovereign default model with an independent central bank that can accumulate a risk-free foreign asset. I show that if the central bank is more patient than the government and as patient as households are, in equilibrium, the government issues more debt than what is socially optimal, and the central bank accumulates reserves to undo government over-borrowing. A key insight is that the government can issue more debt for any level of reserves but chooses not to because doing so would increase spreads, making it more costly to borrow. Quantitatively, I find that the lack of perfect coordination between the central bank and the government can rationalize levels of reserves and debt close to the observed levels in emerging economies.

JEL Codes: E58, F32, F34, F41

Keywords: International Reserves, Central Bank Independence, Sovereign Debt

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1 Introduction

The accumulation of international reserves and public debt in emerging economies is puzzling because economies facing default risk pay high interest rates on their liabilities and receive low interest rates on their reserves.[1] Why, then, do economies paying significant sovereign spreads prefer to accumulate international reserves instead of paying back public debt? Moreover, what is the social welfare effect of reserve accumulation? Even though a large and growing literature addresses these questions, all previous studies have ignored the interaction between the central bank and the government by assuming a consolidated entity that simultaneously chooses reserves and debt.[2] In practice, the central bank often manages international reserves, the government issues public debt, and policymakers may have different incentives driving their choices. This is particularly possible if the central bank is independent from the government. Furthermore, Figure 1 illustrates a positive association between the accumulation of reserves and the widespread adoption of central bank independence (CBI) legislation in Latin America. To the best of my knowledge, this is the first study to explore the role of CBI in the accumulation of international reserves.

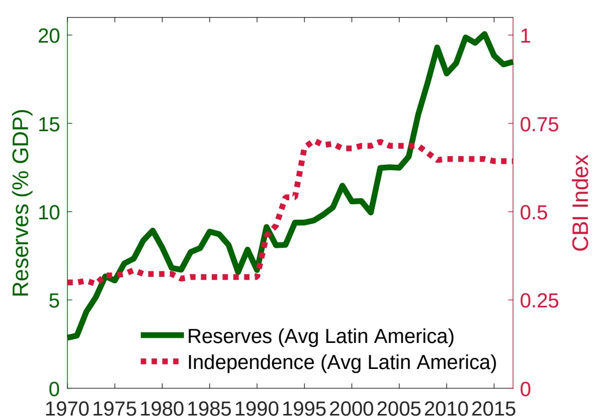


Figure 1: International Reserves and Central Bank Independence

Notes: The figure presents the average levels of international reserves and central bank independence for 11 Latin American countries: Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Mexico, Paraguay, Peru, Uruguay, and Venezuela. The left y axis presents the reserves-to-GDP ratio using data from the IMF and the right y axis reports a *de jure* central bank independence index based on the Cukierman, Webb, and Neyapti index.

[1] Rodrik (2006) estimates that emerging economies incur an annual average GDP loss of 1% by maintaining high levels of reserves and debt.

[2] The assumption of a consolidated entity choosing reserves and debt implies perfect coordination between policymakers. Subsection 2.3 presents evidence on the lack of perfect coordination between the central bank and government.

I use a sovereign default model—Eaton and Gersovitz (1981); Aguiar and Gopinath (2006); Arellano (2008)—enhanced to incorporate an independent central bank that can save in a risk-free foreign asset (i.e. international reserves). As is common in sovereign default models, the government can issue defaultable one-period debt with foreign lenders. I also follow the literature by modelling political pressures as giving the government a low discount factor relative to the foreign lenders.[3] In contrast, I assume that the central bank is more patient than the government is and as patient as households are (i.e. benevolent central bank) to capture the idea that independent central banks operate within institutional frameworks that isolate them from political pressures and that align the central bank's incentives with those of the households.[4] This assumption, which is the main departure from the literature, leads to a disagreement among policymakers about households' intertemporal consumption. I show that, in equilibrium, the lack of perfect coordination between the central bank and government rationalizes simultaneously positive levels of reserves and debt.[5]

On one hand, an impatient government would like to increase its current spending and therefore will issue more debt than what is socially optimal. On the other hand, a benevolent central bank would like to undo government borrowing by accumulating reserves.[6] Because the government could also undo the effects of reserve accumulation by issuing more debt for any level of reserves, why, then, would the central bank choose to accumulate reserves? Consider a portfolio in which the economy is holding zero reserves. For any reserve asset bought by the central bank, the government could issue one bond to undo the effect of the central bank's purchases on the net debt position. However, the government's cost of undoing purchases is increasing in the level of reserves because portfolios having higher levels of reserves and debt implies higher sovereign spreads. Therefore, the government understands that it could undo the effect of reserve accumulation on the net debt position but chooses not to because having higher spreads reduces the amount of consumption that can be front-loaded. Thus, by accumulating international reserves, the central bank has the ability to shift resources toward the future in a way that an impatient government cannot undo.

[3] A well-established political economy literature has provided several models that generate impatient governments. See for example, Alesina and Tabellini (1990) and Persson and Svensson (1989) for closed economies, and Aguiar and Amador (2011) and Cuadra and Sapriza (2008) for environments with external sovereign debt.

[4] See for example, Grilli, Masciandaro, and Tabellini (1991) and Walsh (2003).

[5] In an important early work, Alfaro and Kanczuk (2009) found that canonical sovereign default models with one-period debt cannot rationalize simultaneously positive levels of reserves and debt in equilibrium.

[6] Aguiar, Amador, and Fourakis (2020) identify and quantify the cost of front-loading public spending that arises when an impatient government over-borrows.

It is essential for the mechanism of the model to assume that when a government defaults, international lenders cannot seize the international reserves held by the central bank. Otherwise, the relevant statistic would be the foreign net position, as in Arellano (2008). To illustrate this point, suppose that after a default, a central bank cannot maintain control of its reserves. Therefore, accumulating reserves would increase the repayment value but not the default value. Thus, buying one reserve asset would decrease the probability of default to the same magnitude as increasing debt by one bond, but in the opposite direction. Subsection 2.3 describes the case of Argentina in 2015, which is consistent with this assumption and guarantees that vulture funds will not be allowed to seize the reserves held by an independent central bank.[7]

The model is solved numerically to evaluate its quantitative predictions regarding the levels of international reserves, public debt, and sovereign spreads. I calibrate the model using data for Mexico, a typical emerging economy with an independent central bank, which is a common reference for studies on reserve accumulation. The central bank's discount factor is disciplined by matching the money market interest rate, and the government's discount factor is calibrated internally by targeting public debt.[8] I find that, under the benchmark calibration, model simulations account for 75% of the average level of reserves observed in Mexico from 1994 to 2017. Moreover, I also find that in periods of high income and low spreads, the government increases borrowing and the central bank accumulates more reserves, which accounts for a high and positive correlation between reserves and debt that is consistent with the pattern observed in the data.

Finally, I contrast the baseline model with an economy in which the central bank is as impatient as the government is (i.e. consolidated government). I show that, in accordance with Alfaro and Kanczuk (2009), a sovereign default model with a consolidated government cannot rationalize simultaneously positive levels of debt and reserves. By comparing these two economies, I quantify the welfare gains of having an independent central bank that can accumulate reserves. I find that accumulating reserves by 6.5% of GDP reduces the net debt position by 3.0% of GDP and increases social welfare by 0.1%. Welfare gains come from reducing the costs of front-loading public spending and mitigating the distortion in households' intertemporal consumption.

[7] Any other government agency that is granted independence, such as a sovereign wealth fund, does not have access to the special status that central bank reserves receive in international law.

[8] Alternatively, the central bank's discount factor could be disciplined by the international risk-free interest rate. Subsection 5.1 discusses the role of the main assumption under the benchmark calibration.

Related literature.—This paper mainly contributes to the literature on reserve accumulation, in particular the one using sovereign default models to study the joint dynamics of international reserves, public debt, and sovereign spreads. For example, Alfaro and Kanczuk (2009); Bianchi, Hatchondo, and Martinez (2018); Tavares (2018); and Bianchi and Sosa-Padilla (2020).

Alfaro and Kanczuk (2009), which is closely related to this paper, enhances a sovereign default model to incorporate the possibility that the government accumulates international reserves. They show that, in this framework, the precautionary motive for reserve accumulation does not play a quantitatively important role to account for positive reserve levels because the insurance works by transferring resources to default. Moreover, the model cannot rationalize positive levels of reserves and debt because accumulating reserves is costly and a consolidated government, which is in charge of reserves and debt management, can always get the same net position by reducing debt instead of accumulating reserves. In contrast to Alfaro and Kanczuk (2009), I depart from the assumption of a consolidating government. Instead, I introduce a central bank that is more patient than the government and can accumulate reserves. I show that, by introducing an independent central bank, it is possible to rationalize positive levels of reserves and debt in equilibrium.

Bianchi, Hatchondo, and Martinez (2018) rationalize positive levels of international reserves and public debt in a canonical sovereign default model with long-term debt. They show that when debt maturity exceeds one period, the benefit of accumulating reserves is to provide a hedge against rollover risk. In their model, the consolidated government transfers resources from good times to bad times by accumulating reserves and long-term debt simultaneously. Tavares (2018) explores the role of reserves in sovereign debt restructuring. In his model, accumulating reserves improves lenders recovery rates after default, which implies a drop in sovereign spreads. Bianchi and Sosa-Padilla (2020) study the accumulation of reserves using a sovereign default model with nominal rigidities under a fixed exchange rate. In their model, issuing debt to accumulate reserves allows the government to reduce the average and the volatility of future unemployment. Thus, accumulating reserves provides macroeconomic stability. In contrast to these papers, I depart from the assumption of a consolidated government. Therefore, I contribute to the literature by providing a tractable model of sovereign default and reserve accumulation without assuming perfect coordination between the central bank and the government.[9]

[9] An interesting avenue for future research is to study all of the reserve accumulation motives presented above

Other papers seeking to explain the demand for international reserves have studied the precautionary motive for reserve accumulation. Aizenman and Lee (2007) study the accumulation of reserves in an open-economy version of Diamond and Dybvig (1983), generating endogenous sudden stops. Caballero and Panageas (2008) show that significant gains arise from having financial instruments that provide insurance against sudden stops. Durdu, Mendoza, and Terrones (2009) also model reserve accumulation as insurance against a sudden stop resulting from domestic shocks. Jeanne and Ranciere (2011) model reserves as an Arrow-Debreu security that pays off in a sudden stop, and they provide a simple analytical formula to quantify the optimal amount of reserves. Calvo, Izquierdo, and Loo-Kung (2012) address the optimal level of international reserves in a statistical model by balancing the expected cost of a sudden stop against the opportunity cost of holding reserves. They find that Latin America is closest to model-based optimal levels, while reserves in Eastern Europe lay below optimal levels, and those in Asia lay above. Hur and Kondo (2016) shed light on the upward trend in the reserves-to-debt ratio by studying the accumulation of reserves in a multi-country model with endogenous sudden stops. Jeanne and Sandri (2020) study reserve accumulation using a model in which the private sector can also accumulate a risk-free foreign asset. They show that, even though both private and central bank assets serve as insurance against a sudden stop, only the central bank internalizes the insurance role of reserves and, thus, accumulates international reserves. Cespedes and Chang (2020) study the interaction between optimal reserve accumulation and central bank liquidity provision in a small open economy under financial stress. In their model, accumulating reserves provides liquidity when financial frictions are binding. Arce, Bengui, and Bianchi (2019) propose a macroprudential theory of reserve accumulation by showing that the government accumulates reserves to reduce its exposure to sudden stops due to over-borrowing by the private sector. Their study is closely related to this paper in the sense that the central bank accumulates reserves to mitigate the costs of over-borrowing, but they focus on private over-borrowing instead of on government over-borrowing. In contrast to this strand of the literature, this paper not only endogenizes sudden stops but also the choice of public debt, which is key to understanding the puzzling behavior of the joint dynamics among reserves and public debt observed in emerging economies.

through the lens of my two-policymakers-approach; and determine how these motives for reserve accumulation are affected by the lack of perfect coordination between policymakers.

A different strand of the literature analyzes the role of reserves in implementing exchange rate policies. Obstfeld, Shambaugh, and Taylor (2009) document that countries with a higher level of reserves in 2007 had less exchange rate depreciation during the 2008 crisis. Ghosh, Ostry, and Qureshi (2017) show that central banks in emerging markets engage in foreign exchange interventions to smooth fluctuations in the real exchange rate, selling foreign reserves to prevent depreciation and buying reserves to prevent appreciation. Fratzscher et al. (2019) use daily data on sterilized foreign exchange intervention to test if intervention has the desired effect on the exchange rate; they found that it does. Fanelli and Straub (2018) develop a theory of foreign exchange interventions in a small open economy with limited capital mobility. They show that, in order to avoid excessive currency appreciation, central banks accumulate reserves to lean against the wind of global capital flows. Cavallino (2019) studies foreign exchange interventions as an additional tool to stabilize the economy in the presence of portfolio shocks. Amador et al. (2020) study foreign exchange intervention as a policy when the nominal interest rate is at the zero lower bound. Then, they use the model to show that a violation in interest rate parity generates a capital inflow, which the central bank must absorb by accumulating reserves. Davis, Devereux, and Yu (2020) study how foreign exchange interventions can be used to prevent sudden stops in a small open economy that faces exogenous shocks in its borrowing costs. In contrast to this strand of the literature, my paper abstracts from exchange rate considerations and studies the accumulation of reserves in a real model with a single tradable good. However, I study reserve accumulation in an environment with a lack of perfect coordination between policymakers. One could think, for instance, that this lack of coordination could come from a disagreement between committing to a specific exchange rate policy versus boosting the government's fiscal capacity.[10] Overall, this paper contributes to the literature by providing a novel theory of reserve accumulation that highlights the role of an independent central bank.

Layout.—Section 2 documents that central banks with more independence tend to accumulate more international reserves. Section 3 presents the model. Section 4 illustrates the mechanism for reserve accumulation in a deterministic version of the model. Section 5 describes the model's calibration and presents the quantitative results. Section 6 concludes the paper.

[10] Even though this subject is outside the scope of this paper, the microfoundations of the disagreement between central banks and governments could be an interesting avenue for future research.

2 Facts on Reserves and Central Bank Independence

This section presents empirical evidence on the interaction between reserves and central bank independence. Subsection 2.1 describes the data sources used. Subsection 2.2 documents that central banks with more independence tend to accumulate more reserves. Finally, subsection 2.3 provides anecdotal evidence to support a key assumption of the model.

2.1 Data

I use annual data from 1970 to 2017 for 11 Latin American countries.[11] As is common in the literature, I exclude data for default episodes, following Catao and Mano (2017).

For central bank independence, I use a *de jure* CBI index from Garriga (2016). Following Cukierman, Webb, and Neyapti (1992), the index is based on 16 criteria coded on a scale from 0 to 1 (lowest and highest independence, respectively) and reflects the central banks' political, financial, and policy independence from the government. For international reserves, I use data from the International Financial Statistics. As defined by the IMF (2001), reserves are "official public sector foreign assets that are readily available". This definition includes foreign currencies and foreign-currency deposits and securities, special drawing rights (SDRs), and the reserves position at the IMF. Following the standard convention, I exclude gold. For public debt, I use data from the IMF Historical Public Debt Database for the 1970-2012 period, and from the IMF World Economic Outlook Database for the 2012-2017 period. In line with my motivation, I consider all forms of defaultable public debt. This includes all maturities, and debt denominated in domestic and foreign currency as well as issued domestically or externally. For GDP, I use data from the World Development Indicators Database. For spreads, I use the Emerging Market Bond Index Plus (EMBI+) for the 1994-2017 period. For inflation rates, I use data from the International Financial Statistics.

[11] I focus on this region because, in the early 1990s, most countries in the region approved central bank independence reforms at the same time. The full sample consider for this study includes Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Mexico, Paraguay, Peru, Uruguay, and Venezuela.

2.2 International Reserves and Central Bank Independence

Motivated by a history of dealing with high inflation rates, in the early 1990s, most Latin American countries approved central bank independence reforms to insulate central banks from short-term political pressures and mitigate the inflation bias that may arise under discretionary policy.[12] While the negative correlation between CBI and inflation is a well-established fact,[13] the effect of CBI on the accumulation of foreign assets held by central banks has not been studied.

Because the positive association between CBI and reserves, as presented in Figure 1, could be driven by other confounding factors, I estimate the following panel fixed-effect regression:

$$log\,(A/y)_{i,t} = \alpha_i + \beta_1\,(CBI)_{i,t-1} + \beta_2 log\,(\hat{y})_{i,t-1} + \beta_3 log\,(B/y)_{i,t-1} + \gamma_i + \eta_t + \varepsilon_{i,t}$$

where γ_i represents time-invariant country-fixed effects and η_t denotes time-fixed effects. The term $(A/y)_{i,t}$ denotes the level of reserves, normalized by GDP for country i at time t. All of the explanatory variables are lagged one period to control for endogeneity. In addition, $(CBI)_{i,t}$ denotes the CBI index for country i at period t, $(\hat{y})_{i,t}$ is the cyclical component of GDP for country i at period t, and $(B/y)_{i,t}$ denotes the level of public debt normalized by GDP for country i at period t. The term $\varepsilon_{i,t}$ denotes the regression residuals. In the baseline specification, I include as regressors, all of the variables considered in the theoretical model except for sovereign spreads.[14]

Table 1 shows that, other things equal, the positive correlation between reserve accumulation and central bank independence is robust to various controls and specifications. The regression estimate β_1 can be interpreted as indicating that a one-point increase in *de jure* CBI is associated with a β_1 percent increase in reserves. Specifications (2), (3), and (4) control for other variables commonly used to explain the accumulation of reserves, such as inflation rates, exchange rate regime, and sovereign spreads. The coefficient associated with the inflation rate is negative and significant, which suggests that reserve accumulation is related to inflation rates even after controlling for central bank independence.[15] To control for exchange rate regime, I introduce a dummy variable that

[12] See Rogoff (1985), Waller (1992), Walsh (1995), Svensson (1997), and Walsh (2003).

[13] See Alesina and Summers (1993), Walsh (2008) and Waller (2011). Although the correlation is a well-established fact, the evidence on causality is mixed.

[14] The data available for sovereign spreads starts in 1994, which implies that by considering this variable in the baseline regression, I lose most of the observations from the pre-independence period.

[15] Even though this fact is outside the scope of this paper, an interesting avenue for future research may be to provide

assigns the value "0" to flexible exchange rate regimes and "1" to fixed exchange rate regimes.[16] The coefficient associated with the exchange rate regime implies that countries with fixed exchange rates accumulate more reserves, which is consistent with Bianchi and Sosa-Padilla (2020). Finally, the coefficient associated with sovereign spreads suggests a negative correlation between reserves and spreads, which is inconsistent with the model.[17]

Overall, and to the best of my knowledge, this is the first paper that documents a positive correlation between reserve accumulation and central bank independence.

Table 1: Panel Regressions

	Dependent variable: $log(A/y)$			
	(1)	(2)	(3)	(4)
CBI	$\mathbf{2.36}^{**}$	$\mathbf{2.38}^{**}$	$\mathbf{2.37}^{**}$	$\mathbf{3.45}^{**}$
	(**0.96**)	(**0.92**)	(**0.90**)	(**0.94**)
$log(\hat{y})$	-0.95	-1.41^{**}	-1.42^{**}	-0.65^{**}
	(0.64)	(0.59)	(0.58)	(0.23)
$log(B/y)$	-0.24	-0.18	-0.17	0.21
	(0.30)	(0.28)	(0.27)	(0.17)
inflation		-0.20^{**}	-0.20^{**}	-0.13^{**}
		(0.08)	(0.09)	(0.05)
fx regime			0.05	0.35^{*}
			(0.15)	(0.19)
spreads				-0.47^{**}
				(0.16)
Number of countries	11	11	11	9
Observations	359	359	359	148
R^2	0.47	0.51	0.51	0.61

$^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

a monetary framework that rationalizes the negative correlation between reserve accumulation and inflation rates.

[16] I use the fine classification codes from Ilzetzki, Reinhart, and Rogoff (2017).

[17] Subsection 5.2 discusses the main reason for this discrepancy between the model and the data.

2.3 Supportive Anecdotal Evidence

This subsection provides anecdotal evidence that supports a key assumption of the model: the central bank's capability to retain its reserves when the government defaults.

International Reserves after Default.—In August 2015, the Argentinian central bank won the reversal of a U.S. court ruling that had allowed bondholders to try to hold the central bank responsible for the debt that had been defaulted in 2002. According to *Reuters*, "The 2nd U.S. Circuit Court of Appeals in New York overturned a 2013 ruling denying a bid by Banco Central de la Republica Argentina (BCRA) to dismiss claims by U.S. investment firms holding $2.4 billion in judgments against the South American country. U.S. District Judge Thomas Griesa had previously held that the central bank had waived its sovereign immunity, and that as a result, the hedge funds could move forward with a lawsuit targeting the central bank's assets."[18] This case set an international precedent and guarantees that vulture funds would not be allowed to seize the international reserves held by the central bank when the government defaults on its foreign liabilities. Moreover, the case of Argentina in 2015 illustrates that central bank's reserves receive a special status in international law that is not received by any other government agency that is granted independence, such as a sovereign wealth fund.

3 Model

This section presents a dynamic small-open economy model in which households receive a stochastic endowment, the government issues non-state-contingent defaultable debt, and the central bank buys a reserve asset that pays a risk-free interest rate. The model extends the seminal work of Eaton and Gersovitz (1981) by adding an independent central bank, and is similar to Alfaro and Kanczuk (2009) except for the assumption that the government behaves as a consolidated entity.

[18]U.S. Appeals Court says bondholders cannot seize Argentina's reserves, *Reuters*, August 31, 2015.

3.1 Environment

Endowments.—Time is discrete and indexed by $t \in \{0,1,...\}$. The economy's endowment of the single tradable good is denoted by $y \in \Re_{++}$. The endowment process is given by

$$log(y_t) = \rho log(y_{t-1}) + \varepsilon_t,$$

where $|\rho| < 1$ and $\varepsilon_t \sim N(0, \eta^2)$.

Households.—The representative household has preferences given by

$$\mathbb{E}_\tau \left\{ \sum_{t=\tau}^{\infty} \beta^t u(c_t) \right\}, \tag{1}$$

where $\mathbb{E}$ denotes the expectation operator conditional on information at time τ, β is the households' discount factor, and c is private consumption. The utility function $u : \Re_+ \to \Re$ is strictly increasing and strictly concave. The households' budget constraint is given by

$$c_t = (1 - \tau^\pi) y_t + T_t, \tag{2}$$

where $T_t \in \Re$ denotes lump-sum transfers from the government and $\tau^\pi \in \Re_{++}$ is an exogenous inflation tax collected by the central bank. I assume that the inflation tax is exogenous and constant over time.[19]

Two Policymakers.—The economy is populated by a government and a central bank. Both policymakers maximize the same utility function as households but they differ in their discount factors. Therefore, the objective function of policymaker $j \in \{F, M\}$ is given by

$$\mathbb{E}_\tau \left\{ \sum_{t=\tau}^{\infty} (\beta^j)^t u(c_t) \right\},$$

where β^F and β^M denote the discount factors of the government and the central bank, respectively.

[19] Appendix D illustrates that the monetary base is the main driver of the change in the level of reserves. Therefore, in the absence of money in the model, I assume an exogenous source of income for the central bank which is captured by $\tau^\pi y_t$. The assumptions that (i) inflation tax τ is constant over time and (ii) transfers from the government to the central bank are allowed (i.e., fiscal support) imply no correlation between reserve accumulation and inflation rates, which is consistent with the data. See Table 10.

In particular, I assume that the government is more impatient relative to the central bank and households, i.e., $\beta^F < \beta^M = \beta$. This assumption, which is key for most results in this paper, is meant to capture the idea that an independent central bank may be more patient than the government about the use of reserves to finance a public deficit.[20]

Previous studies assume a consolidated government, with a high degree of impatience, which chooses simultaneously reserve and debt levels. In contrast, I introduce a government that issues public debt and a central bank that accumulates reserves. While the assumption of a high degree of impatience is reasonable for the government given the insight of Alesina and Tabellini (1990) and Persson and Svensson (1989), which show that political turnover generates in effect a low discount factor for the government; this assumption may not be accurate for an independent central bank, which operates in an institutional framework that isolates it from short-term political pressures and that align the central bank' incentives with those of the households.[21]

Central Bank's Budget Constraint.—The central bank can use seigniorage, $\tau^{\pi}y$, to buy a risk-free foreign asset, $A \in \Re_{+}$, that pays one unit of consumption good in the next period and is traded at a constant price q^*. I also assume that transfers between policymakers, $\Omega \in \Re$, are allowed.[22] Therefore, a large accumulation of reserves could be financed not only by seigniorage but also by transfers from the government to the central bank, which is consistent with the data in the sense that the monetary base and government transfers are the main drivers of the change in the level of reserves (see Figure 8). Therefore, the central bank's budget constraint is given by

$$q^* A_{t+1} + \Omega_t = \tau^{\pi} y_t + A_t, \tag{3}$$

where A_t denotes the central bank's reserves holdings at the beginning of period t and A_{t+1} represents the level of reserves chosen by the central bank during period t.

[20] For instance, in December 2010, Argentina President Cristina Fernandez de Kirchner announced a plan to use reserves to pay back debt and the central bank president, Martin Redrado, refused to support her plan. This case illustrates the potential disagreement that may arise when policymakers have different incentives driving their choices about the adequate use of reserves.

[21] On these two arguments see Grilli, Masciandaro, and Tabellini (1991), and Walsh (2003).

[22] While $\Omega_t > 0$ denotes a positive transfer from the central bank to the government at period t, $\Omega_t < 0$ implies fiscal support. In practice, central banks transfer their surplus annually to the government. However, most central banks can also transfer resources indirectly by buying government bonds. Moreover, in the case of Mexico, government bonds are not assets but liabilities that represents around 5.4% of GDP, which supports the assumption of fiscal support. See Figure 6

Government's Budget Constraint.—The government can issue non-state contingent one-period debt $B \in \Re_+$ at price q, which in equilibrium depends on the amount of debt issued, the new stock of reserves, and the exogenous shocks. As in canonical sovereign default models, the government lacks commitment and it can choose to default at any time. The government also receives (makes) transfers from (to) the central bank. Finally, the government can transfer resources to the households. Therefore, the government's budget constraint is given by

$$T_t + B_t = q_t B_{t+1} + \Omega_t, \tag{4}$$

where B_t denotes liabilities at the beginning of period t and B_{t+1} represents the amount of bonds issued in period t.

Resource Constraint.—By consolidating the budget constraints of the households, central bank, and government—eq. (2), (3), and (4)—we obtain a standard expression for the resource constraint

$$c_t = y_t - B_t + A_t + q_t B_{t+1} - q^* A_{t+1}. \tag{5}$$

Default.—When the government defaults, I assume exclusion from financial markets with reentry probability $\theta \in (0,1)$, an exogenous default cost, and zero recovery rate (i.e. fraction of the loan that lenders recover after a default).[23] I follow Arellano (2008) and Chatterjee and Eyingungor (2012) by capturing default costs (e.g. reputation costs, sanctions, and misallocation of resources) as an income loss $\phi(y)$, which is increasing in income.

As discussed in subsection 2.3, I assume that if the government defaults on its foreign liabilities then the lenders cannot seize the central bank's reserves and the central bank still has access to financial markets. Even though this is a standard assumption in the literature and is consistent with observed default episodes, it is important to mention that this is key for my results. Otherwise, the central bank cannot offset government borrowing by accumulating reserves and the relevant statistic would be the net debt as in Arellano (2008).

Therefore, the resource constraint during default is given by

$$c_t = y_t - \phi(y_t) + A_t - q^* A_{t+1}. \tag{6}$$

[23] All these assumptions are common in the literature.

Foreign Lenders and Risk Premium.—There is a continuum of identical foreign lenders of measure one. They have perfect information regarding the endowment process of the economy and can observe the level of income, debt, and reserves every period. We assume that foreign lenders price bonds' payoffs using a stochastic discount factor, m, given by

$$m_{t,t+1} = e^{-r^* - (\kappa_t \varepsilon_{t+1} + 0.5\kappa_t^2 \eta^2)}, \tag{7}$$

where ε and η are the parameters governing the income process, r^* denotes the discount rate, and $\kappa_t \geq 0$ represents risk premium shocks. This specification of the lenders' discount factor delivers a time-varying endogenous risk premium on sovereign bonds that captures disturbances to financial markets that are exogenous to local conditions.[24] The risk premium shock follows a two-state Markov process with values $\kappa_L = 0$ and $\kappa_H > 0$, and transition probabilities π_L and π_H. In normal times, $\kappa_t = \kappa_L = 0$, lenders are risk neutral as in Arellano (2008). Otherwise, $\kappa_t = \kappa_H > 0$, lenders become risk averse and require a higher expected return to buy government bonds.[25] This shock plays an important role matching the distribution of spreads that we observe in the data, but it is not crucial for the core mechanism of reserve accumulation presented in this paper. [26]

Disagreement between Policymakers.—In the model, the accumulation of reserves is driven by the assumption of two policymakers with different discount factors. This assumption leads to a disagreement among policymakers about households' intertemporal consumption. On one hand, the impatient government would like to increase current spending and therefore issues more debt than what is socially optimal. On the other hand, the benevolent central bank (i.e. patient central bank) would like to transfer resources toward the future and therefore improves the net position of the economy as a whole. Since policymakers have different policy instruments to affect the net debt position of the economy, defined as $N \equiv B - A$, the disagreement among policymakers could

[24] This specification of the lenders' discount factor is a special case of the discrete-time version of the Vasicek (1977) one-factor model of the term structure, and it has been used in other sovereign default models such as Arellano and Ramanarayanan (2012), and Bianchi, Hatchondo, and Martinez (2018).

[25] A higher value of κ_H can be seen as capturing the correlation between the small open economy's GDP and the lenders' income process, or alternatively, the degree of diversification of foreign lenders.

[26] The appendix presents an alternative calibration where I abstract from the risk-premium shock to emphasize the conflict of interest among government entities as the main force for reserve accumulation.

be illustrated by rewriting the resource constraint—eq. (5)—as follows

$$c_t = y_t - N_t + q_t B_{t+1} - q^* A_{t+1}, \tag{8}$$

where the third term of the RHS, $q_t B_{t+1}$, illustrates that government can front-load consumption by issuing debt, and the fourth term of the RHS, $q^* A_{t+1}$, illustrates that by accumulating reserves the central bank can reduce consumption today to transfer resources toward the future. Furthermore, equation (8) illustrates that the bond prices play a key role for the mechanism of the model. While the price of international bonds q^* is constant, the domestic bond price schedule q_t is a function of the policymakers' choices due to the endogenous probability of default. As in Arellano (2008), the bond price schedule is decreasing in debt because the new level of debt only affects negatively tomorrow's repayment value but not tomorrow's default value, which increases the probability of default and decreases the bond price schedule. In contrast, the new level of reserves affects both the repayment and default values. Subsection 5.3 shows that the central bank's ability to shift resources toward the future in a way that cannot be undone by the government depends on the dynamics of the bond price schedule and reserves.

Timing.—The timing of actions within each period is as follows:

1. Shocks, $s_t = (y_t, \kappa_t)$ are realized, and the aggregate state of the economy is given by (s_t, B_t, A_t).
2. The government chooses whether or not to default, $D_t = \{0, 1\}$.
   (a) If default occurs, $D_t = 1$, the government is excluded from financial markets and the central bank chooses the new level of reserves, A_{t+1}.
   (b) Otherwise, $D_t = 0$, policymakers move simultaneously: the government issues new debt, B_{t+1}, taking as given the bond price schedule, $q_t(s_t, B_{t+1}, A_{t+1})$, and the central bank chooses the new level of reserves, A_{t+1}.[27]
3. Households consume, c_t.

[27]The assumption about the central bank and the government moving simultaneously responds to the tractability of the model. Future research should extend the model to a sequential game. In a two-period model, it is easy to prove that there is a first-mover advantage and the mechanism presented in this paper only holds when the central bank moves first. However, this first-mover advantage should disappear in an infinitely repeated game.

3.2 Recursive Problems

I focus on Markov perfect equilibria, where policymakers' strategies depend only on payoff-relevant-state variables. Since households simply consume their endowment after transfers, and lenders provide the amount of debt demanded by the government, as long as the expected return on domestic bonds equals the return on the risk-free foreign asset, $\frac{1}{q^*}$, the only two strategic agents in the model are the policymakers. Therefore, we can interpret this environment as a simultaneous game in which the government makes default and debt choices in period t taking as given the central bank's strategy, and vice versa, the central bank chooses the new level of reserves at period t taking as given the government's strategy. We now drop time subscripts and move to the recursive formulation where x and x', respectively, indicate current and future values of variable x.

Government.—Let $V^F(s,B,A)$ be the value function of the government that faces the state (s,B,A) and has the option to default. Given a bond price schedule q, the function V^F satisfies the following functional equation:

$$V^F(s,B,A) = \max_D \left\{(1-D)\cdot V_r^F(s,B,A) + D\cdot V_d^F(s,A)\right\}, \tag{9}$$

where V_r^F denotes the government's repayment value given by

$$V_r^F(s,B,A) = \max_{B'} \left\{u(c) + \beta^F \mathbb{E}[V^F(s',B',A')|s]\right\},$$

subject to

$$c = y + A - B - q^* A' + q(s,B',A')B',$$

$$A' = \hat{A}_r(s,B,A),$$

and V_d^F represents the government's default value given by

$$V_d^F(s,A) = u(c) + \beta^F(\theta\mathbb{E}[V^F(s',0,A')|s] + (1-\theta)\mathbb{E}[V_d^F(s',A')|s]),$$

subject to

$$c = y - \phi(y) + A - q^* A'$$

$$A' = \hat{A}_d(s, A),$$

where $\hat{A}_r(s,B,A)$ and $\hat{A}_d(s,A)$ denote the central bank's decision rules for reserves accumulation in repayment and default states, respectively.

The solution to equation (9) yields decision rules for default, $\hat{D}(s,B,A)$, and debt issuance, $\hat{B}(s,B,A)$. The default rule is equal to 1 if the government defaults and is equal to 0 otherwise. In the recursive equilibrium, lenders use these decision rules, as well as the decision rules for reserves, to price debt contracts. The decision rules for reserves solve the central bank's recursive problems described below.

Central Bank.—The central bank's choice of reserves accumulation depends on whether the government has access to financial markets. In repayment states, the central bank's value function V_r^M is given by

$$V_r^M(s,B,A) = \max_{A' \geq 0} \left\{ u(c) + \beta^M \mathbb{E}[(1-D') \cdot V_r^M(s',B',A') + D' \cdot V_d^M(s',A') | s] \right\}, \tag{10}$$

subject to

$$c = y + A - B - q^* A' + q(s,B',A')B',$$

$$B' = \hat{B}(s,B,A),$$

$$D' = \hat{D}(s',B',A'),$$

where $\hat{B}(s,B,A)$ denotes today's debt choice, $\hat{D}(s',B',A')$ represents tomorrow's default choice, and V_d^M is the central bank's value function in default states given by

$$V_d^M(s,A) = \max_{A' \geq 0} \left\{ u(c) + \beta^M (\theta \mathbb{E}[V_r^M(s',0,A')|s] + (1-\theta)\mathbb{E}[V_d^M(s',A')|s]) \right\}, \tag{11}$$

subject to

$$c = y - \phi(y) + A - q^{*}A'.$$

Solution to equation (10) yields a decision rule for reserve accumulation in repayment, $\hat{A}_r(s,B,A)$. The third and fourth lines of this equation illustrate that if the government has access to financial markets, the central bank takes as given the government's strategy. Consequently, households' consumption is determined by the policymakers' interaction. In contrast, equation (11) illustrates that if the government is excluded from financial markets, households' consumption is exclusively determined by the central bank through its decision rule for reserve in default, $\hat{A}_d(s,A)$.

Bond Price Schedule.—Bond prices compensate lenders for their risk-adjusted opportunity cost:

$$q(s,B',A') = \mathbb{E}[m(s,s') \cdot (1 - \hat{D}(s',B',A'))|s], \tag{12}$$

where bond prices depend not only on the debt issued but also on the new stock of reserves. Subsection 5.3 shows that the portfolio composition is relevant to determine the bond prices, and not only the net debt position of the economy. Finally, we use lenders' stochastic discount factor and their portfolio condition—eq. (7) and (12)—to get an expression for the risk-free foreign bond price, given by

$$q^{*} = e^{-r^{*}}. \tag{13}$$

3.3 Recursive Equilibrium

A Markov perfect equilibrium for this economy is defined by (i) a set of value functions V^F, V_r^M, and V_d^M; (ii) decision rules for default $\hat{D}$, borrowing $\hat{B}$, reserves in default $\hat{A}_d$, reserves in repayment $\hat{A}_r$, and consumption $\hat{c}$; and (iii) a bond price function q such that:

1. Given q, policy functions $\{\hat{D},\hat{B}\}$ solve the government's problem—eq. (9).

2. Given q, policy function $\hat{A}_r$ solves the central bank's problem in repayment—eq. (10).

3. $\hat{A}_d$ policy function solves the central bank's problem in default —eq. (11).

4. Given policymakers' policies, policy function $\hat{c}$ satisfies the resource constraint.

5. Given policymakers' policies, q satisfies the lender's no arbitrage condition—eq. (12).

4 Deterministic Case

To illustrate that the lack of perfect coordination between policymakers can rationalize positive levels of international reserves and public debt, I begin by considering a deterministic version of the model in which endowments are known at period 0, $y_t = 1$ for all t, and there is no risk-premium shock, $\kappa_t = 0$ for all t. I also assume that the reentry probability is zero, $\theta = 0$, and the exogenous default cost is given by $\phi(y) = \gamma$, where $0 < \gamma < 1$. Therefore, the endowment after default is given by $y^{def} = (1-\gamma)$. In this environment, there is no default in equilibrium. Instead, there is an endogenous borrowing limit that represents the maximum level of debt such that the government is willing to repay. Lenders know that for any level of debt above the borrowing limit, the government's optimal choice is to default on its liabilities. Therefore, they will not lend more than this amount. In this section, I show that in debt-constrained economies in which the government issues more debt than what is socially optimal, an independent central bank has the ability to discipline the net debt position of the economy by accumulating reserves.[28]

Proposition 1 characterizes the endogenous borrowing limit. Proposition 2 characterizes the equilibrium for an economy in which the central bank is as impatient as the government (i.e. consolidated government), which is equivalent to the deterministic version of Alfaro and Kanczuk (2009). Proposition 3 characterizes the equilibrium for an economy populated by a social planner (i.e. as patient as households) choosing the optimal allocations of debt and reserves. Proposition 4 shows that the baseline model rationalizes positive levels of reserves and debt. Corollary 1 shows that, in the baseline model, the central bank can implement the optimal net debt position of the economy by accumulating reserves.

Proposition 1 *(Characterization of the borrowing limit). Let $\bar{B}$ denotes the borrowing limit.*

If $\beta^M = \beta = q^*$ then $\bar{B} = \frac{\gamma}{1-q*}$.

Proof. See appendix.

Proposition 1 tell us that, under some assumptions, the borrowing limit does not depend on the level of reserves. This result follows from assuming that the central bank discounts the future at

[28]This section also shows that the mechanism for reserve accumulation presented in this paper does not depend on the precautionary motive, which is common in the literature.

the same rate as households and the rest of the world. This assumption enables me to analytically characterize the borrowing limit and illustrate in a simple way the main mechanism of the model.

Proposition 2 *(Consolidated Government Equilibria) Let B_t^{alf} and A_t^{alf} denote, respectively, debt and reserves levels in equilibrium. For any initial level of debt and reserves, B_0 and A_0, $\exists\, \bar{t}$ such that if $\beta^F = \beta^M < \beta = q^*$ then $B_t^{alf} = \bar{B}$ and $A_t^{alf} = 0$ for all $t > \bar{t}$.*

Proof. See appendix.

Proposition 2 tell us that a consolidated government does not accumulate reserves. This result, consistent with Alfaro and Kanczuk (2009), is driven by the impatience of the government relative to the rest of the world. Since a consolidated government can get the same net debt position through different combinations of reserves and debt, when the borrowing constraint is binding an impatient government has no incentives to hold positive levels of reserves. Otherwise, the portfolio of reserves and debt is undetermined. Figure 2a illustrates that, in this specific example, the government consumes its reserves in the first period and borrows up to the borrowing limit in the next four periods. Even though it is possible to observe positive levels of reserves in the first four periods, a consolidated government would eventually deplete the reserves and borrow up to the borrowing limit due to its relative impatience.

Proposition 3 *(Social Planner Equilibria) Let B_t^{SP} and A_t^{SP} denote, respectively, debt and reserves levels in equilibrium. For any initial levels of debt and reserves, B_0 and A_0, if $\beta^F = \beta^M = \beta = q^*$ then $\forall\, B_t \in [B_0, \bar{B}]$ $\exists\, A_t \geq 0$ such that:*

1. $B_t^{SP} = B_t$,
2. $A_t^{SP} = A_t$,
3. $N_t^{SP} = B_t - A_t = B_0 - A_0$.

Proof. See appendix.

Proposition 3 illustrates that in an economy populated by a benevolent social planner (i.e. consolidated government as patient as households), there are multiple combinations of reserves and debt that can constitute an equilibrium as long as the net debt position is the same. Therefore, the optimal net debt position is unique and equal to the initial net debt level.

Proposition 4 *(Independent Central Bank Equilibria) Let B_t^* and A_t^* denote, respectively, debt and reserves levels in equilibrium. For any initial level of debt and reserves, B_0 and A_0, if $\beta^F < \beta^M = \beta = q^*$ then $B_t^* = \bar{B}$ and $A_t^* > 0$ for all $t > 0$.*

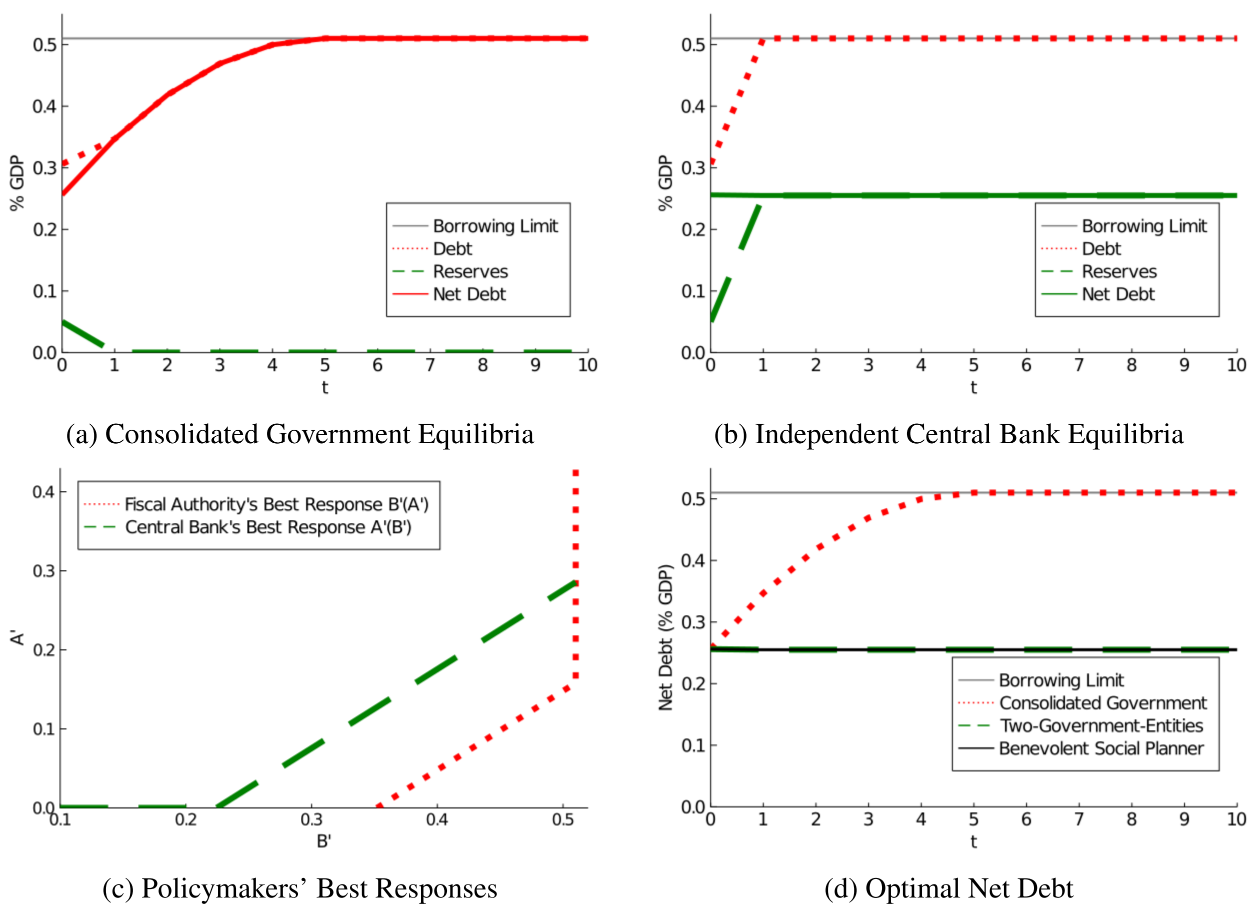
Proof. See appendix.

Corollary 1 *(Optimal Net Debt) Let B_t^* and A_t^* denote, respectively, debt and reserves levels in the independent central bank equilibria. For any initial levels of debt and reserves,B_0 and A_0, the net debt position is given by $N_t^* = B_t^* - A_t^* = N_t^{SP}$.*

Proposition 4 tell us that, if the central bank is more patient than the government, in equilibrium, the economy holds positive levels of reserves and debt. This result follows from the assumption of different discount factors, which leads to a disagreement between policymakers. On one hand, the impatient government prefers to front-load consumption and therefore issues more debt than what is socially optimal. On the other hand, the central bank prefers to smooth consumption and accumulates reserves to shift resources toward the future. Since policymakers have different policy tools to affect the net debt position of the economy, the equilibrium is such that the government borrows up to the borrowing limit and the central bank accumulates reserves to offset government over-borrowing. Figure 2b illustrates that the central bank accumulates reserves as long as the impatient government issues debt. Thus, the net debt position of the economy remains constant.

The lack of perfect coordination between policymakers leads to a simultaneous game where the government uses debt markets to front-load consumption and the central bank accumulates international reserves to smooth consumption. Figure 2c illustrates policymakers' best responses given initial debt and reserve levels. While the central bank's best response is increasing in debt, the government's best response is increasing in reserves. Therefore, in equilibrium the central bank accumulates reserves to push the government to the borrowing limit and discipline the net debt position of the economy. Thus, the central bank's ability to discipline the net debt position depends on the fact that the government is debt-constrained. Otherwise, the government can undo the effect or reserve accumulation on the net debt position by issuing more debt.

While in the deterministic model the existence of an endogenous borrowing limit is guaranteed by assuming that the government lacks commitment and debt is defaultable, in the stochastic model these two assumptions imply a spread on interest rates that makes it costly for the government to undo the effect of reserve accumulation by issuing more debt. Subsection 5.3 shows that the government could undo the central bank's choice of reserves but chooses not to because it does perceive that spreads are going up and this reduces the amount of consumption that can be front-loaded. Finally, corollary 1 tell us that an independent central bank can implement the optimal net debt position by accumulating international reserves. Figure 2d illustrates that, in equilibrium, the net debt position of the economy in which the central bank is independent from the government is equal to the net debt position chosen by a benevolent social planner (i.e. optimal net debt). This result is driven by the fact that in the deterministic environment there is no spreads on interest rates and therefore accumulating reserves is costless. While this is no longer true in the stochastic environment because the default risk implies a spread on interest rates, subsection 5.4 shows that accumulating reserves is still welfare improving.



(a) Consolidated Government Equilibria

(b) Independent Central Bank Equilibria

(c) Policymakers' Best Responses

(d) Optimal Net Debt

Figure 2: Consolidated Government vs Independent Central Bank

5 Quantitative Analysis

In this section, I present the quantitative analysis of the model. Subsection 5.1 presents the benchmark calibration. Subsection 5.2 presents key statistics in the data and model simulations. Subsection 5.3 inspects the mechanism of the model. Subsection 5.4 explores the social welfare implications of having an independent central bank that can accumulate international reserves.

5.1 Calibration

Functional Forms.—The utility function with constant relative risk aversion is given by

$$u(c) = \frac{c^{(1-\sigma)}}{1-\sigma},$$

with $\sigma \neq 1$, and I follow Chatterjee and Eyingungor (2012) by adopting the functional form for default costs given by

$$\phi(y) = max\{0, d_0 y + d_1 y^2\}.$$

Parameter Values.—The model is solved numerically to evaluate its quantitative predictions regarding the level of international reserves, public debt, and sovereign spreads. The appendix describes the computation of the model. I calibrate the model using data for Mexico from 1994 to 2017, a typical emerging economy with an independent central bank used commonly as a reference for studies on reserves accumulation.[29] A period in the model refers to a year. I choose a subset of parameter values (summarized in table 2) that can be directly pinned down from the data, and then I choose a second subset of parameter values (summarized in table 3) such that model simulations match key aspects of the data.

The risk aversion parameter value ($\sigma = 2$) is standard in quantitative business cycle and sovereign default studies. The international risk-free interest rate is set to match the average real interest rate for US Treasury Bills from 1980 to 2017, which is set to 1.1% ($r^* = 0.011$). I use spreads from the EMBI+ to parameterize the lenders' stochastic discount factor. I assume that a period with high risk aversion is one in which the global EMBI+ is one standard deviation above the median over the sample period. With this procedure, I obtain 6 episodes of high risk premium every 20

[29]The time period starts in 1994 because the Mexican central bank independence reform was approved in 1993.

years with an average duration equal to 0.7 years, which implies $\pi_{LH} = 0.3$ and $\pi_{HL} = 0.8$.[30] The parameter values that govern the endowment process are chosen to mimic the behavior of logged and linearly detrended GDP. The estimation of the stochastic process for the cyclical component of GDP yields $\rho = 0.66$ and $\eta = 0.034$. I set the reentry probability to match an average duration in financial exclusion of 9 years, which corresponds to the time period in which Mexico was excluded from financial markets in its last default episode (1982-190). This yields $\theta = 0.11$. Finally, the central bank's discount factor is disciplined by the average money market interest rate observed in Mexico during the period that the central bank has been independent. This is a real interest rate of 3.5%, which implies $\beta^M = 0.966$.[31]

There are four parameters calibrated by simulation: the government's discount factor β^F, the parameters associated with the exogenous default cost d_0 and d_1, and the pricing kernel parameter κ_H. I choose these four parameters to match four targets in the data: (i) an average public debt of 44.4% of GDP, (ii) an average level of spreads of 267 basis points, (iii) an increase in the spread during high risk premium periods of 296 basis points, which is the average increase in the sovereign spread observed in Mexico during the three high risk premium episodes identified in the data, and (iv) a historical probability of default equal to 2%, which is a rough estimate based on the 2 default episodes observed in Mexico in the last 100 years according to Catao and Mano (2017). The government's discount factor mainly determines the average debt level, the values of the default cost mainly determine the behavior of spreads, and the pricing kernel parameter is mainly disciplined by the probability of default.[32]

I use total public debt data from IMF datasets. While this data includes domestically held and long-term debt, in the model all domestic bonds mature in one period and are held by foreigners.[33]

[30] On average, the global EMBI+ was 2 percentage point higher in those episodes than in normal periods.

[31] The role of this calibration strategy is to approximate the behavior of the central bank not only through an instrument that is close to the policy rate but also to the domestic economic conditions. Alternatively, we could assume that the central bank and households are as impatient as foreign lenders. For instance, Samano (2022a) calibrates the model for the Argentinean economy and assumes that the central bank is as impatient as foreign lenders. The main result of this exercise is that the model rationalizes reserve levels three times higher that the observed levels in Argentina from 1993 to 2017. This alternative calibration could be interpreted as the counterfactual in which the central bank is completely isolated from political pressure, while the benchmark calibration is closer to the observed degree of central bank independence.

[32] While having both the default probability and the mean spread as calibration targets is not standard in the literature, this allows the model to match high spread levels, even with one-period-bonds, without implying a high default probability which is not consistent with the data.

[33] Total public debt data also includes debt denominated in domestic and foreign currency, while the model implicitly assumes that the real exchange is equal to one so there is no distinction between domestic and foreign currency.

Since the model is not rich enough to consider many debt instruments, there is a trade-off when choosing the debt instrument that disciplines the model. While there is no perfect way to solve this trade-off, I choose to target total public debt because it is the most general instrument that approximates the impatient behavior of the government. In the appendix, I present an alternative calibration in which the government's discount factor is calibrated to match debt service.[34]

Table 2: Parameters Calibrated from the Data

Parameter	Description	Value	Source / Target
σ	Risk aversion	2	Alfaro and Kanczuk
r^*	International risk-free interest rate	0.011	US Treasury bills rate = 1.1%
π_{LH}	Probability of transiting to high risk premium	0.30	Global EMBI +
π_{HL}	Probability of transiting to low risk premium	0.80	Global EMBI +
ρ	Auto-correlation of y	0.66	Mexico's GDP
η	Variance of y	0.034	Mexico's GDP
θ	Reentry probability	0.11	9 years in default (1982-1990)
β^M	Central Bank's discount factor	0.966	MX money market rate = 3.5%

Table 3: Parameters Calibrated by Simulation

Parameter	Description	Value	Target
β^F	Government's discount factor	0.939	Debt to GDP = 44.4%
d_0	Default cost parameter	-0.809	Average spread = 267 bp
d_1	Default cost parameter	0.902	Increase in spread = 296 bp
κ_H	Pricing kernel parameter	0.27	Default probability = 2%

[34] While Appendix C shows that the mechanism proposed in the paper survives with a calibration that targets debt service, it also shows that the chosen calibration target is very important quantitatively. Reserves with the alternative calibration are only half of the reserves in the baseline. In any case, the model sheds light on how the lack of perfect coordination between the central bank and the government could rationalize positive levels of reserves and debt.

5.2 Key Statistics: Model vs Data

Now, I report long-run moments in the data and in the model simulations.[35] Table 4 shows that model simulations match the calibration targets. Table 5 shows that the model also does a good job in mimicking the behavior of reserves and debt. In particular, model simulations rationalize a reserves-to-GDP ratio of 6.5%, which corresponds to 75% of the average level of reserves observed in Mexico from 1994 to 2017 (8.7% of GDP). Moreover, the model matches a high and positive correlation between reserves and debt observed in the data, as well as the pro-cyclical behavior of reserves. Most of these results are consistent with Bianchi, Hatchondo, and Martinez (2018).[36]

The model also generates volatile spreads and a high correlation between consumption and income, which is consistent with previous studies that do not consider reserve accumulation such as Aguiar and Gopinath (2006) and Arellano (2008). The model generates a spread volatility that is higher than the observed in Mexico, but it is close to the median for emerging market economies documented by Bianchi, Hatchondo, and Martinez (2018). The model does a good job matching the correlation of sovereign spreads with debt and output shocks but it delivers a positive correlation between spreads and reserves that is not consistent with the data. This is explained by the fact that, in the model, reserve holdings make default episodes less painful and increases the incentives to default. However, the model abstracts from other benefits of having reserves that could explain the negative correlation between spreads and reserves observed in the data.[37] There are other shortcomings of the quantitative exercise mainly driven by the one-period-bond assumption. For instance, a sovereign debt model with one-period-bond cannot replicate high level of spreads unless we assume a high risk premia shock, which is what explains the low correlation between spreads and income reported in Table 5. While the one-period-bond assumption is convenient due to tractability of the model, future research should study the quantitative implications of adding long-term bonds. In any case, this simple model sheds light on the implications of relaxing the assumption of perfect coordination between the central bank and the government.

[35] Moments in the model are computed by generating 1,000 simulations samples of 500 periods each and taking the last 50 observations of samples in which the last default was observed at least 25 periods before the beginning of the sample.

[36] In contrast with their model, I do not consider long-term debt. By considering only one-period bonds, I abstract from the hedging motive against rollover risk and explore the central bank independence channel as a mechanism for reserve accumulation.

[37] For example, Tavares (2018) studies the role of reserves in debt restructuring and shows that having reserves increases lenders recovery rates after default, which implies a drop in sovereign spreads ex-ante.

To emphasize my contribution to the literature, I contrast the workings of the baseline model with an economy in which the central bank is as impatient as the government, this is $\beta^M = \beta^F = 0.939$. The rest of the parameter values are the same as in the benchmark calibration. By doing so, I can replicate the results by Alfaro and Kanczuk (2009), in the sense that a canonical sovereign debt model with one-period bonds cannot simultaneously rationalize high levels of reserves and debt. Table 6 not only illustrates this fact but also shows that the probability of default is higher in the baseline model than in the consolidated government economy. In the economy populated by an independent central bank, the probability of default is 1.8%, while in the consolidated government economy the probability of default is only 0.5%. Even though the consolidated government economy is not re-calibrated, because this would change the degree of impatience of the government and these two economies would not be comparable, the fact that the probability of default increases when the central bank is independent from the government is somehow counter-intuitive. As I mentioned above, reserve holdings help to mitigate default costs and increase the incentives to default. Alternatively, we could interpret this result as a commitment device that is costly due to the lack of perfect coordination between the government and the central bank.

Table 4: Targeted Moments

	Data	Model
mean B/y (%)	44.4	44.4
mean r_s (%)	2.7	2.7
$\Delta\,(r_s)$ for $\kappa = \kappa_H$ (%)	3.0	4.0
default prob (%)	2.0	1.8

Table 5: Non-targeted Moments

	Data	Model
mean (A/y) (%)	**8.7**	**6.5**
corr $(A/y, B/y)$	0.6	0.8
corr $(A/y, y)$	0.7	0.4
corr (c, y)	0.8	0.8
std (r_s) (%)	1.3	4.0
corr (r_s, y)	0.0	0.0
corr $(r_s, B/y)$	0.1	0.1
corr $(r_s, A/y)$	-0.4	0.1
$\sigma(c)/\sigma(y)$	1.0	1.1

Table 6: Independent Central Bank vs Consolidated Government

	Data	Baseline Model	Consolidated Government
mean (A/y) (%)	**8.7**	**6.5**	**0.3**
mean B/y (%)	44.4	44.4	41.1
mean r_s (%)	2.7	2.7	2.6
Δ (r_s) for $\kappa = \kappa_H$ (%)	3.0	4.0	4.3
default prob (%)	2.0	1.8	0.5

5.3 Central Bank Independence Channel

The accumulation of international reserves in the model is driven by the assumption of different discount factors, which leads to a disagreement between the central bank and government about households' intertemporal consumption. This disagreement can be illustrated by considering two economies where reserves and debt are chosen by the same policymaker. Let $\bar{A}^F(s,B,A)$ and $\bar{B}^F(s,B,A)$ denote policy functions for reserves and debt in an economy that is only populated by the government (i.e. $\beta^F = \beta^M < \beta$), also called consolidated government economy. For a given aggregate state, the households' consumption can be expressed by rewriting the resource constraint (eq. 5),

$$\bar{c}^F(s,B,A) = y - B + A + q(s,B',A')B' - q^*A', \tag{14}$$

where $B' = \bar{B}^F(s,B,A)$ and $A' = \bar{A}^F(s,B,A)$.

Now, I consider an economy where the benevolent central bank chooses reserves and debt ($\beta^F = \beta^M = \beta$). Let $\bar{A}^M(s,B,A)$ and $\bar{B}^M(s,B,A)$ denote policy functions for reserves and debt in such an economy, also called the social planner economy. Analogously, households' consumption can be expressed as

$$\bar{c}^M(s,B,A) = y - B + A + q(s,B',A')B' - q^*A', \tag{15}$$

where $B' = \bar{B}^M(s,B,A)$ and $A' = \bar{A}^M(s,B,A)$.

Figure 3 illustrates the disagreement between policymakers by plotting policy functions for consumption for the consolidated economy and the social planner economy, $\bar{c}^F(s,B,A)$ and $\bar{c}^M(s,B,A)$ respectively. Panel (a) shows that, given the aggregate state, the impatient government would choose to deliver higher consumption today to the households than what the benevolent central bank would choose. This disagreement is represented by the difference in consumption. Panel (b) illustrates that the disagreement about intertemporal consumption implies a discrepancy about the desirable net debt position of the economy, where the government would choose to issue more debt than what is socially optimal.

In the baseline model, policymakers not only disagree about intertemporal consumption but also have different policy tools to affect the net debt position of the economy as a whole. In particular, the impatient government would like to front-load consumption by issuing debt and the central bank would like to transfer resources toward the future by accumulating reserves. Therefore, the benefit of accumulating international reserves in the model depends on the central bank's ability to reduce the net debt position of the economy and affect the equilibrium consumption. To illustrate this point, it is convenient to see how consumption decreases when the central bank accumulates reserves

$$\frac{\partial \hat{c}(s,B,A)}{\partial A'} = -q^* + \frac{\partial q(s,\hat{B}(s,B,A),A')}{\partial A'}\hat{B}(s,B,A), \tag{16}$$

where the first term, $-q^*$, illustrates that the central bank has to pay q^* units of consumption today to buy one risk-free asset, and the second term represents that accumulating reserves also affects the units of consumption delivered to the households when the government is issuing B' bonds. However, for any level of reserves, the government can undo the effect of the accumulation of reserves by issuing more debt. This is

$$\frac{\partial \hat{c}(s,B,A)}{\partial B'} = q(s,B',A') + \frac{\partial q(s,B',\hat{A}_r(s,B,A))}{\partial B'}\hat{B}(s,B,A), \tag{17}$$

where the first term, $q(s,B',A')$, illustrates that by issuing debt the government can deliver $q(s,B',A',)$ units of consumption to the households plus the marginal effect of issuing one more bond on the price schedule, which is denoted by the second term.

Equations 16 and 17 illustrate that the interaction between the bond price schedule and the level of reserves and debt is crucial to understand the mechanism of the model. Figure 4a shows that the bond price schedule is decreasing in debt as in standard sovereign default models, but it is almost constant on the accumulation of international reserves. This result holds because, in contrast to debt levels, the reserves level affects both the default value and the repayment value for the government. Therefore, a change in the level of international reserves does not substantially change the incentives to default for the government, thus the bond price schedule is almost flat on the accumulation of reserves. Figure 4b shows that both default and repayment values increase on the level of reserves, almost at the same rate, without changing the default incentives for the government.

To show that sovereign risk is crucial for the central bank's ability to offset over-borrowing by the government, suppose that there is no default risk. Therefore, the price of domestic bonds is equal to the price of foreign bonds for any aggregate state, $q(s,B',A') = q^*$, and neither reserves nor debt affect the bond prices. This is

$$\frac{\partial q(s,\hat{B}(s,B,A),A')}{\partial A'} = \frac{\partial q(s,B',\hat{A}_r(s,B,A))}{\partial B'} = 0,$$

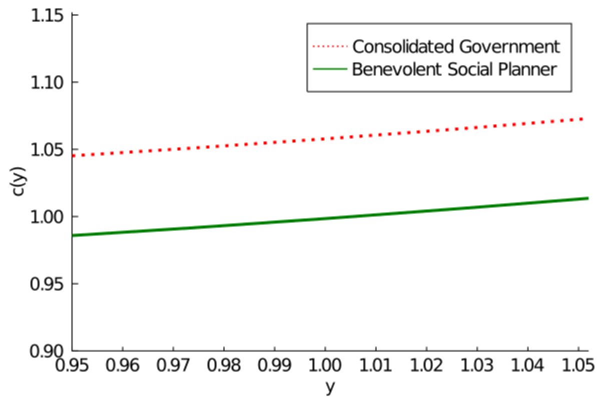
which implies that by issuing one more bond the government delivers q^* units of consumption and, vice versa, the central bank transfers one unit of consumption from today to tomorrow by buying one bond at price q^*. This is,

$$\left|\frac{\partial \hat{c}(s,B,A)}{\partial A'}\right| = \left|\frac{\partial \hat{c}(s,B,A)}{\partial B'}\right| = q^*.$$

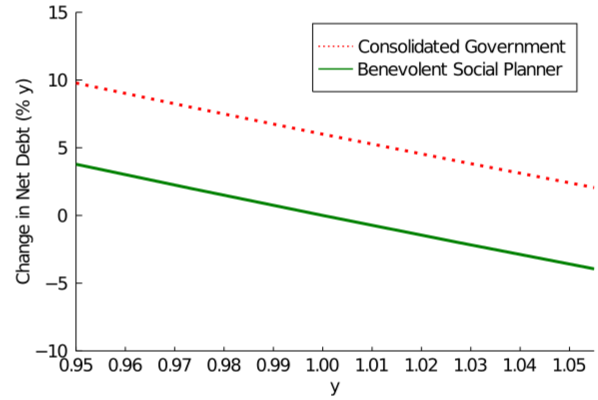
Therefore, the spread on interest rates, $r_s = \frac{1}{q} - \frac{1}{q^*}$, is key to undo government borrowing because it increases the cost of holding portfolios with high levels of reserves and debt.

Figure 5 shows portfolios of reserves and debt that would deliver the same consumption as in equilibrium. Solid dots represent choices of reserves and debt in equilibrium, $(\hat{A}_r(s,B,A),\hat{B}(s,B,A))$, given the aggregate state (s,B,A). Panel (a) illustrates that for any level of international reserves, the government can issue more debt to undo the effect of the central bank's choice on the net debt position, and vice versa, the central bank can accumulate reserves to undo government borrowing. This figure also illustrates that the government issues more debt in periods of high income than in low income periods, and the central bank accumulates more reserves in high income periods than in low income periods. While the pro-cyclical behavior of debt is a common feature of sovereign default models, the pro-cyclical behavior of reserves follows from the fact that the central bank accumulates more reserves when the government over-borrows more. Panel (b) shows that the sovereign spread is increasing in portfolios with higher levels of reserves and debt, which increases the cost of reversing the effect of the central bank's choice on the equilibrium consumption.

In a nutshell, by accumulating international reserves, the central bank has the ability to shift resources toward the future in a way that cannot be undone by the government due to the sovereign spreads faced by the economy.

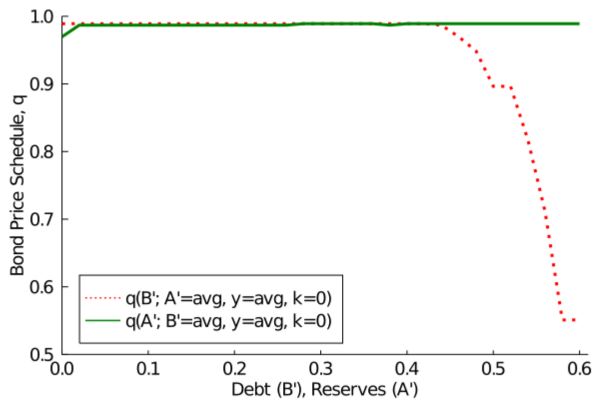


(a) Difference in Consumption

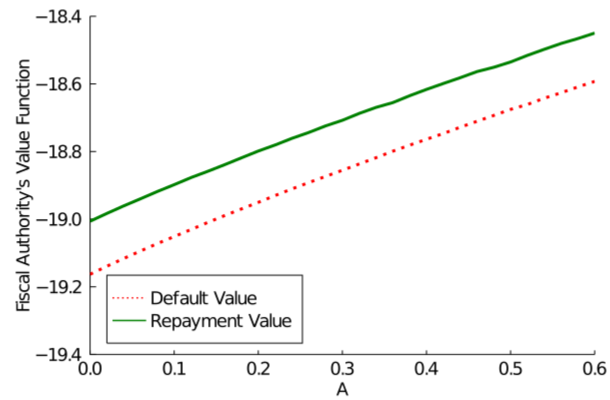


(b) Difference in Net Debt

Figure 3: Disagreement between Policymakers

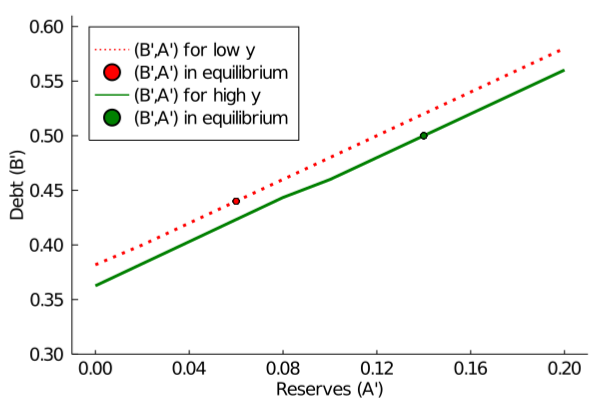


(a) Bond Price Schedule

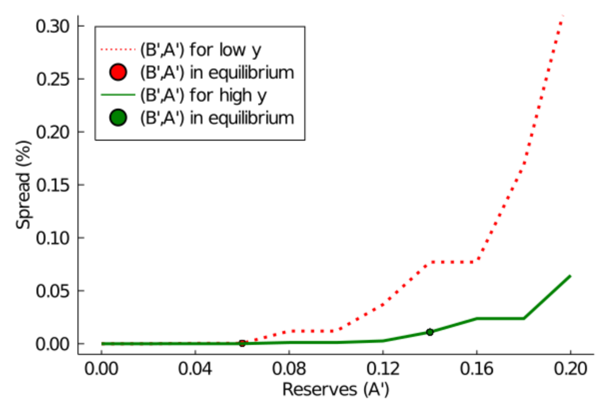


(b) Government's Value Function

Figure 4: International Reserves and Sovereign Risk



(a) Portfolios of Reserves and Debt



(b) Cost of Accumulating Reserves

Figure 5: Reserves and Debt Choices

5.4 Welfare Analysis

Now, I explore the question of whether accumulating reserves is welfare improving. On one hand, the central bank accumulates international reserves to undo government over-borrowing. On the other hand, this is costly because using reserves to pay back debt reduces spreads. To quantify the welfare gains of accumulating reserves, I contrast the baseline model with the consolidated government economy (i.e. $\beta^M = \beta^F = 0.939$). This section shows that, by accumulating reserves, an independent central bank can transfer resources towards the future in a way that cannot be undone by an impatient government, reducing the net debt position of the whole economy and increasing social welfare.

To calculate the welfare gains of having an independent central bank that accumulates reserves, I proceed as follows. First, I take as a starting point a draw from the ergodic distribution of the consolidated government economy (y, κ, B, A). Then, I simulate a series of shocks $\{(y, \kappa)\}_{t=1}^{T}$ for $T = 1000$. Using policy functions for the consolidated government economy and the baseline model, I compute the consumption path for both economies $\{(c_t^{NoInd}, c_t^{Indep})\}_{t=1}^{T}$. Then, I take $N = 1000$ draws of these consumption paths $C = \{\{(c_t^{NoInd}, c_t^{Indep})\}_{t=1}^{T}\}_{n=1}^{N}$ and define:

$$V_{Indep}(C) = E\left[\sum_{t=1}^{\infty} \beta^{t-1} u(c_t^{Indep})\right] \approx \sum_{t=1}^{T} \frac{1}{N} \sum_{n=1}^{N} \beta^{t-1} u(c_{t,n}^{Indep})$$

and

$$V_{NoInd}(C, \lambda) = E\left[\sum_{t=1}^{\infty} \beta^{t-1} u((1+\lambda) c_t^{NoInd})\right] \approx \sum_{t=1}^{T} \frac{1}{N} \sum_{n=1}^{N} \beta^{t-1} u((1+\lambda) c_{t,n}^{NoInd}),$$

where V_{Indep} is the value of having an independent central bank who accumulates reserves, V_{NoInd} is the value of having a consolidated government who controls choices of reserves and debt, and λ denotes a compensation to the households in the economy that does not have an independent central bank. I define welfare gains λ^* as the compensation such that households are indifferent between having and not having an independent central bank, $V_{Indep}(C) = V_{NoInd}(C, \lambda^*)$. By substituting the functional form for the utility function, we get

$$\lambda^* = \left(\frac{\sum_{t=1}^{T} \frac{1}{N} \sum_{n=1}^{N} \beta^{t-1} (c_{t,n}^{Indep})^{1-\sigma}}{\sum_{t=1}^{T} \frac{1}{N} \sum_{n=1}^{N} \beta^{t-1} (c_{t,n}^{NoInd})^{1-\sigma}} \right)^{\frac{1}{1-\sigma}} - 1.$$

By following this procedure, I estimate $\lambda^* = 0.0007$. Thus, having an independent central bank that can accumulate reserves to offset government borrowing increases social welfare by 0.1%.

6 Conclusion

This paper proposes a novel theory of reserve accumulation that emphasizes the role of an independent central bank in three key aspects: (i) independence allows central banks to manage their reserves without interference from the government, (ii) an independent central bank may be more patient than the government and more prudent about the use of reserves to finance a public deficit, and (iii) even if the government defaults on its foreign liabilities, the central bank's reserves cannot be appropriated by disgruntled creditors. I show that these three elements together can account for a rise in international reserves that coincides with the widespread adoption of central bank independence legislation in Latin America.

I use a quantitative sovereign default model enhanced to incorporate an independent central bank to assess whether it can quantitatively account for the fact that countries facing significant sovereign spreads hold simultaneously large levels of international reserves and public debt. The main contribution of this paper is to provide a new channel for reserve accumulation. I find that, by accumulating reserves, an independent central bank is able to shift resources toward the future in a way that cannot be undone by an impatient government. Quantitatively, I show that the lack of perfect coordination between the central bank and the government can rationalize levels of reserves and debt close to the observed levels in emerging economies.

Overall, this paper provides a tractable framework to study the joint dynamics of international reserves, public debt, and sovereign spreads without assuming perfect coordination between the central bank and the government. I believe an interesting avenue for future research may be to study other reserve accumulation motives through the lens of my two-policymakers-approach; and determine how these motives are affected by the lack of perfect coordination among policymakers.

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Appendix A. Proofs

A1. Proof of Proposition 1

The proof relies on two claims that are straightforward to prove and guarantee a stationary state.
Claim 1: If $B = \bar{B}$ then $B' = \bar{B}$. This result follows from the fact that when the government is more impatient relative to the international lenders and the borrowing limit is binding, the optimal policy is to rollover debt such that $B' = \bar{B}$.
Claim 2: If $\beta^M = q^*$ then $\hat{A}_d(1,A) = A$ and $\hat{A}_r(1,\bar{B},A) = A$. This result follows from the fact that when the central bank discounts the future at the same rate as the international lenders, the optimal policy is to rollover assets such that $A' = A$ for all $A \geq 0$.
The rest of the proof follows from the definition of borrowing limit:

$$V_r^F(1,\bar{B},A) = V_d^F(1,A),$$

$\iff$ (by definition)

$$\frac{u(1+(1-q^*)(A-\bar{B}))}{1-\beta^F} = \frac{u(1-\gamma+(1-q^*)A)}{1-\beta^F},$$

$\iff$ (by strictly concavity of u)

$$1+(1-q^*)(A-\bar{B}) = 1-\gamma+(1-q^*)A,$$

$\iff$

$$\bar{B} = \frac{\gamma}{1-q^*} \blacksquare$$

A2. Proof of Proposition 2

When there is a consolidated government (i.e. $\beta^F = \beta^M < q^*$) choosing simultaneously reserves and debt, the relevant statistic is the net debt position defined as

$$N_t^{alf} = B_t^{alf} - A_t^{alf}.$$

Due to the impatience of the government relative to the international lenders, we know that

$$N_0^{alf} < N_1^{alf} < N_2^{alf} < ... < N_{\bar{t}}^{alf} = \bar{B},$$

for some $\bar{t}$. We also know that the optimal policy once the borrowing limit is binding is to rollover debt, this is

$$N_t^{alf} = \bar{B},$$

for all $t > \bar{t}$. This implies

$$N_t^{alf} = B_t^{alf} - A_t^{alf} = \bar{B},$$

for all $t > \bar{t}$. Finally, due to the impatience of the government we know that the government would try to deplete any positive amount of reserves in equilibrium, therefore it must be true that $A_t^{alf} = 0$ and $B_t^{alf} = \bar{B}$ for all $t > \bar{t}$ ■

A3. Proof of Proposition 3

When there is a social planner (i.e. $\beta^F = \beta^M = q^*$) choosing simultaneously reserves and debt, as in Proposition 2, the relevant statistic is the net debt position defined as

$$N_t^{SP} = B_t^{SP} - A_t^{SP}.$$

Since the central bank discounts the future at the same rate as the international lenders, we know that, for all t, the optimal policy is given by

$$N_t^{SP} = N_0^{SP}.$$

By definition, $N_t^{SP} = B_0 - A_0$. Therefore, $\forall\ B_t \in [B_0, \bar{B}]$ we can choose $A_t = B_t - B_0 + A_0 > 0$. Thus, $\forall\ B_t \in [B_0, \bar{B}]$

1. $B_t^{SP} = B_t$,
2. $A_t^{SP} = B_t - B_0 + A_0$,
3. $N_t^{SP} = B_t - A_t = B_0 - A_0$ ■

A4. Proof of Proposition 4

From Proposition 2, we know that $\beta^F < q^*$ implies that for some $\bar{t}$

$$B_0^* < B_1^* < B_2^* < ... < B_{\bar{t}}^* = \bar{B}.$$

Given a sequence of debt levels chosen by the government, $\{B_0^*, B_1^*, B_2^*, ..., B_{\bar{t}}^*\}$, we know from Proposition 3 that there exists a sequence of reserve levels chosen by the central bank, $\{A_0^*, A_1^*, A_2^*, ..., A_{\bar{t}}^*\}$, such that $N_t^* = B_t^* - A_t^* = B_0 - A_0$, for all t. In particular, we know that for all $t > \bar{t}$

$$A_t^* = \bar{B} - B_0 + A_0 > 0.$$

Finally, it is straightforward to prove that $\bar{t} = 1$. Suppose not. This implies that $B_1^* < \bar{B}$. Let $B_1^* = \bar{B} - \varepsilon$, for $\varepsilon > 0$. Then, we know that the central bank would optimally choose $A_1^* = \bar{B} - \varepsilon - B_0 + A_0$. However, ($\bar{B} - \varepsilon$, $\bar{B} - \varepsilon - B_0 + A_0$) cannot be an equilibrium because the government would always have incentives to issue more debt, up to ε, due to its impatience relative to the central bank and the rest of the world. This is true for all $\varepsilon > 0$. Therefore, the only equilibrium would be (B_1^*, A_1^*) = ($\bar{B}$, $\bar{B} - B_0 + A_0$). Thus, (B_t^*, A_t^*) = ($\bar{B}$, $\bar{B} - B_0 + A_0$), for all t ■

Appendix B. Computational Algorithm

The following algorithm is used to solve the model:

1. Start with a guess for the bond price schedule such that $q(s,B',A') = e^{-r^*}$ for all (s,B',A').

2. Start with a guess for the central bank's repayment value such that $V_r^M(y,\kappa,B,A) = V_r^M(1,0,B,A)$ for all (y,κ,B',A'), where $V_r^M(1,0,B,A)$ is the value function that solves the central bank's recursive problem in the deterministic case.

3. Solve the recursive problem of the central bank in default using value function iteration, and get the policy function for reserves accumulation in default $\hat{A}_d(s,A)$.

4. Solve the government's recursive problem and get policy functions for default choice and debt issuance, $\hat{D}(s,B,A)$ and $\hat{B}(s,B,A)$.

5. Solve the recursive problem of the central bank in repayment using value function iteration, and get the policy function for reserves accumulation in repayment $\hat{A}_r(s,B,A)$.

6. Repeat (2)-(6) until the guess converges to the central banks repayment value.

7. Estimate the bond price schedule using the probability of default as in Arellano (2008).

8. Repeat (2)-(7) until the guess converges to the bond price schedule.

Appendix C. Alternative Calibrations

Targeting Debt Service

In the benchmark calibration, I choose to target total public debt because it is the most general instrument that approximates the impatient behavior of the government. However, in the model there are only one-period bonds as in Arellano (2008). Therefore, in this appendix, I present an alternative calibration in which the government's discount factor is calibrated to match the debt service. The main result of this section is that, under the alternative calibration, the model still rationalizes positive levels of reserves equal to 3.3% of GDP.

Parameter Values.—While the parameters values pinned down from the data are exactly the same as in Table 2, some parameters calibrated by simulation have changed: the government's discount factor and the default cost parameter. The government's discount factor increased from $\beta^F = 0.939$ to $\beta^F = 0.954$ and the default cost parameter decreased from $d_0 = -0.809$ to $d_0 = -0.894$ in order to match a lower debt level without assuming a discount factor higher than the central bank's discount factor. In summary, table 7 presents the alternative parameter values.

Table 7: Alternative Parameters Calibrated by Simulation

Parameter	Description	Value	Target
β^F	Government's discount factor	0.954	Debt Service to GDP = 5.5%
d_0	Default cost parameter	-0.894	Average spread = 267 bp
d_1	Default cost parameter	0.902	Increase in spread = 296 bp
κ_H	Pricing kernel parameter	0.27	Default probability = 2%

Key Statistics.—Table 8 shows that model simulations under the alternative calibration deliver similar results as in the benchmark calibration. In particular, model simulations still rationalize positive reserve levels equal to 3.3% of GDP. Moreover, the model matches a high and positive correlation between reserves and debt observed in the data, as well as the pro-cyclical behavior of reserves. Under this alternative calibration, the model also delivers low correlations between sovereign spreads and variables such as output, debt, and reserves. Even though the low correlation is consistent with the data in most cases, it is important to mention that spreads in the model are mainly driven by the risk premium shocks. The fifth column of table 8 shows key statistics for an economy under the alternative calibration without risk premium shocks, this is $\kappa = 0$. Model simulations show that, in this case, the spreads are positively correlated with the output shocks. Interestingly, this behavior is completely opposite from the one observed in the standard canonical model and it is driven by the fact that during good times the government issues more debt and the central bank accumulates more reserves, which increases the probability of default.

Overall, this section shows that the main result of this paper is robust to alternative calibrations that target debt service instead of public debt and do not consider risk premium shocks. In any case, my sovereign debt model with an independent central bank can simultaneously rationalize positive levels of reserves and debt due to the lack of perfect coordination between policymakers.

Table 8: Benchmark vs Alternative

	Data	Benchmark	Alternative	No Risk Premium
Targeted Moments				
mean B/y (%)	44.4 / 5.5	44.4	5.5	8.5
mean r_s (%)	2.7	2.7	2.6	0.1
Δ (r_s) for $\kappa = \kappa_H$ (%)	3.0	4.0	3.9	
default prob (%)	2.0	1.8	1.7	1.3
Non-targeted Moments				
mean $(\mathbf{A/y})$ (%)	**8.7**	**6.5**	**3.3**	**1.8**
corr $(A/y, B/y)$	0.6	0.8	0.6	0.8
corr $(A/y, y)$	0.7	0.4	0.3	0.4
corr (c, y)	0.8	0.8	0.9	0.9
std (r_s) (%)	1.3	4.0	3.9	0.2
corr (r_s, y)	0.0	0.0	0.0	0.5
corr $(r_s, B/y)$	0.1	0.1	0.1	0.1
corr $(r_s, A/y)$	−0.4	0.1	0.0	0.2

Appendix D. Supportive Empirical Evidence

This section documents four facts that support the assumption that reserves are financed either through seignoraige or transfers from the government.

1. International reserves constitute the main asset of central banks among emerging economies.

2. Government bonds do not play an important role in the asset side of the CB's balance sheet.

3. Monetary base and government transfers are the main drivers of the change in reserve levels.

4. Changes in the monetary base are not highly and positively correlated with inflation rates.

Data

I follow Sosa-Padilla and Sturzenegger (2021) by using an IMF dataset that provides standardized data for the central bank's balance sheet from 2002 to 2018. Due to data availability the sample includes Algeria, Belarus, Belize, Brazil. Bulgaria, Colombia, Dominican Republic, Egypt, Georgia, Ghana, Indonesia, Jamaica, Jordan, Kazakhstan, Mexico, Morocco, Nigeria, Pakistan, Peru, Philippines, Russian Federation, Senegal, South Africa, Sri Lanka, Thailand, Tunisia, Turkey, Ukraine. The table below summarizes the items in the central bank's balance sheet:

Claims on non-residents (1)	Liabilities to non-residents (a)
Claims others depository corporations (2)	Monetary base (b)
Net Claims on Central Government (3)	Other Liabilities to Other Depository Corporations (c)
	Deposits and Securities other than Shares Excluded from the Monetary Base (d)
	Loans (e)
	Financial Derivatives (f)
	Shares and equity (g)
	Other items (h)

Table 9: Central Bank's Balance Sheet

Then, I construct the following variables:

- **Reserve Ratio** = (1) / GDP,
- **Government Bonds** = (3) / GDP,
- **External Liabilities** = (a) / GDP,
- **Money Ratio** = (b) / GDP,
- **Domestic Liabilities** = [(c) + (d) + (e) + (f)] / GDP,
- **Other Balance Sheet** = [(g) + (h) - (2)] / GDP,

where the first variable, Reserve Ratio, is the total claims on non-residents (largely made up of gross reserves), which is the number typically used in the literature. Government Bonds denotes the net claims on Central Government. External liabilities denote liabilities incurred with non-residents. Money Ratio is the monetary base. Domestic Liabilities is the amount of remunerated liabilities issued by the central bank in domestic currency. Other Balance Sheet denotes the remaining terms of the balance sheet.

To show that changes in the level of reserves are mainly driven by changes in the monetary base, I use the central bank's balance sheet to write an equation for the reserve ratio given by

$$A_t = -B_t^G + b_t + b_t^* + M_t + \varepsilon_t, \tag{18}$$

where A_t denotes the reserve ratio, B_t^G represents government bonds, b_t denotes domestic liabilities, b_t^* denotes foreign liabilities, M_t represents the money ratio, and ε_t denotes the remaining terms. Taking changes at time t+1 yields:

$$\Delta A_{t+1} = \Delta \omega_{t+1} + \Delta b_{t+1} + \Delta b_{t+1}^* + \Delta M_{t+1} + \Delta \varepsilon_{t+1}, \tag{19}$$

where ω_{t+1} represents positive transfers from the government to the central bank, defined as the negative of government bonds, i.e., $\omega_{t+1} \equiv -B_{t+1} = -\Omega_{t+1}$. Since there is data available for all the variables defined above, we can express the change in the level of reserves as changes in government transfers, domestic liabilities, external liabilities, monetary base, and the remaining terms of the balance sheet.

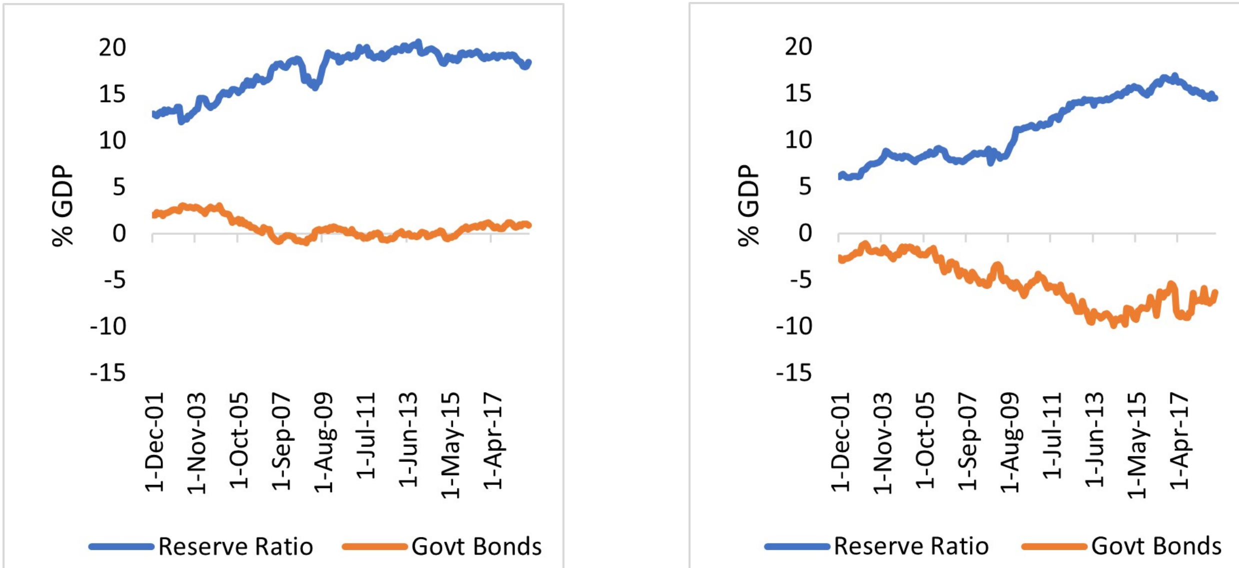
Facts

Figure 6 shows that (i) international reserves constitute the main asset of central banks among emerging economies, and (ii) government bonds do not play an important role in the left side of the central banks' balance sheet. Panel (a) illustrates that the average level of reserves among emerging economies represents 17.5% of GDP, while domestic government bonds held by the central bank only represents 0.7% of GDP. Moreover, panel (b) illustrates that, in the case of Mexico, government bonds are not assets but liabilities that represents 5.4% of GDP, which not only justifies assumption A1 but also supports the assumption that the accumulation of reserves could be partially financed through transfers from the government to the central bank (i.e., fiscal support), which is implicit in the model when $\Omega_t < 0$.[38]

Turning to the right side of the central bank's balance sheet, Figure 7 shows that the monetary base is the main component of central bank liabilities, as Referee #2 pointed out. Moreover, Figure 8 illustrates that changes in the level of reserves are mainly associated to changes in the monetary base.[39] However, Table 10 shows that changes in the monetary base are not positively correlated with inflation rates, which implies that an increase in the monetary base is not simple translated into an increase in inflation. For instance, the median correlation between inflation and changes in both monetary base and reserves is close to zero (-0.03 and 0.03, respectively), while the change in the monetary base and the change in the reserve levels are highly and positively correlated (0.7). Even though this finding is puzzling because standard monetary theory shows that, under some assumptions, an increase in the monetary base is followed by an increase inflation, one could think that an increase in the monetary base, which is associated to an increase in the level of reserves, could lead to exchange rate depreciation rather than inflationary pressures. Since this is out of the scope of this paper, I let the further study of this puzzling co-movement for future research. In any case, the evidence presented above suggests that the monetary base plays an important role financing the accumulation of reserves. Therefore, in the absence of money in the model, we need to assume an exogenous source of income for the central bank, which is captured by $\tau^{\pi} y_t$.

[38] The previous version of the paper assumes lack of fiscal support, i.e., $\Omega_t > 0$ for all t. Motivated by this fact, the new version of the paper assumes that fiscal support is allowed, i.e., $\Omega_t \in \Re$ for all t.

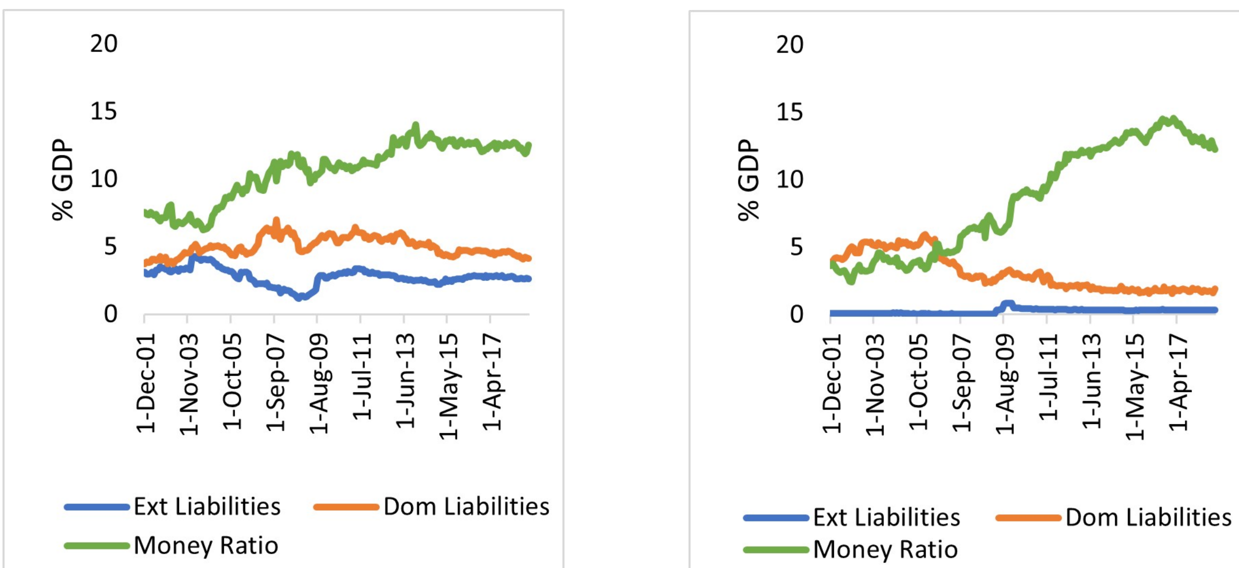
[39] The methodology followed for this exercise is presented in Appendix A.



(a) EMEs

(b) Mexico

Figure 6: Central Bank Assets



(a) EMEs

(b) Mexico

Figure 7: Central Bank Liabilities

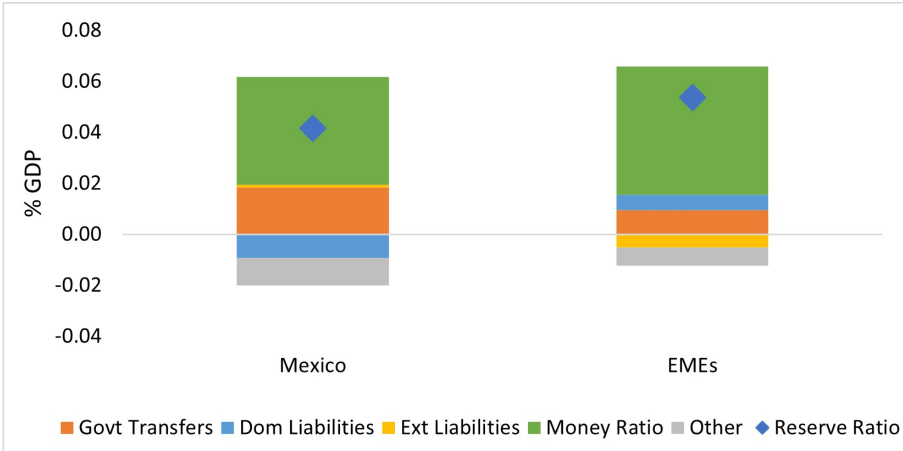


Figure 8: Drivers of the Change in the Level of Reserves

Notes: The figure presents the average monthly change from January of 2002 to December of 2018 for the following variables: government transfers, domestic liabilities, external liabilities, monetary base, and the remaining terms of the balance sheet. The blue dot denotes the monthly change in the level of international reserves.

	Inflation, %Δ Money	Inflation, %Δ Reserves	%Δ Money, %Δ Reserves
Algeria	-0.39	-0.35	0.67
Belarus	0.33	0.42	0.68
Brazil	-0.02	0.09	-0.08
Bulgaria	0.08	0.07	0.97
Colombia	0.01	0.02	0.76
Dominican Republic	-0.12	0.06	0.58
Egypt	0.08	0.07	-0.58
Georgia	-0.03	0.06	0.85
Ghana	-0.02	0.06	0.21
Indonesia	0.01	0.00	0.40
Jamaica	-0.07	-0.02	0.40
Jordan	-0.23	0.09	0.37
Mexico	-0.18	-0.13	0.76
Morocco	0.02	0.06	0.85
Nigeria	-0.02	0.03	0.69
Pakistan	-0.20	-0.18	0.72
Peru	0.01	-0.10	0.38
Philippines	0.01	-0.04	0.30
Russia	-0.17	-0.17	0.97
Senegal	-0.09	-0.12	0.97
South Africa	-0.08	-0.07	0.56
Sri Lanka	-0.17	-0.14	0.81
Thailand	-0.21	0.11	0.28
Tunisia	0.00	0.00	0.85
Turkey	-0.03	0.07	0.57
Ukraine	-0.08	0.11	0.75
Median	**-0.03**	**0.03**	**0.69**

Table 10: Correlations between Inflation with Reserves or Monetary Base