International Reserves and Central Bank Independence*

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Abstract

This paper proposes a novel theory of reserve accumulation that emphasizes the role of an independent central bank in an environment in which the government lacks fiscal discipline. Motivated by a positive correlation between central bank independence and the accumulation of international reserves in Latin America, I develop a quantitative 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 the households, 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 it would increase sovereign spreads, making it more costly to borrow. Quantitatively, I show that the central bank independence channel accounts for 83% of the average level of reserves observed in Mexico from 1994 to 2017. I find that accumulating reserves by 7.2% of the GDP reduces the net debt position by 3.3% of GDP and increases social welfare by 0.1%.

JEL Codes: E58, F32, F34, F41

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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 debt 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? Although is a large and growing literature that addresses these questions, all previous studies ignore the interaction between the central bank and the government by assuming a consolidated entity simultaneously choosing reserves and debt.[2] In practice, reserves are often managed by the central bank, public debt is issued by the government, 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 legislation in Latin America. To the best of my knowledge, this is the first study that explores the role of central bank independence (CBI) on the accumulation of international reserves.

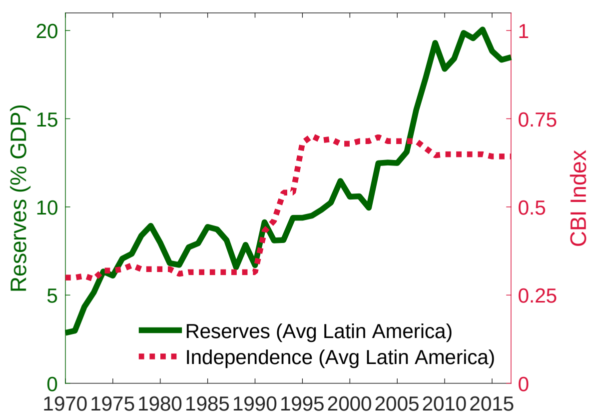


Figure 1: International Reserves and Central Bank Independence

Notes: The figure presents the average level of international reserves and central bank independence for 11 Latin American countries, which include 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 coordination between policymakers. Subsection 2.3 presents evidence of the lack of coordination between the central bank and the 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 and as patient as households (i.e. benevolent central bank) to capture the idea that independent central banks operate in 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, this conflict of interest between the central bank and the government rationalizes simultaneously positive levels of reserves and debt.[5]

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 would like to undo government over-borrowing by accumulating reserves.[6] Since 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 where the economy is holding zero international 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 with higher levels of reserves and debt imply 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 higher spreads reduce 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 cannot be undone by the government.

[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) identifies and quantifies 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, 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 default the 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 in the same magnitude, but in a different direction, as increasing debt by one bond. This assumption is not only consistent with the case of Argentina in 2015, but also highlights why it is an independent central bank, and no other government agency, that can offset government borrowing by accumulating international reserves.[7]

The model is solved numerically to evaluate its quantitative predictions regarding the level 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 that is a common reference for studies on reserve accumulation. I discipline the central bank's discount factor by matching the domestic money market interest rate, while the government's discount factor is calibrated internally by targeting total public debt.[8] I find that, under the benchmark calibration, model simulations account for 83% 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 over-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 where the central bank is as impatient as the government (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 7.2% of GDP, reduces the net debt position by 3.3% 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] The Argentinean case, described in subsection 2.3, guarantees that vulture funds will not be allowed to seize the reserves held by an independent central bank. 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] By following this calibration strategy, the model is able to match high levels of debt without implying an outrageous domestic interest rate as standard default models when assuming a low discount factor.

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) rationalizes positive levels of reserves and 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 simultaneously reserves and long-term debt. Tavares (2018) explores the role of reserves in sovereign debt restructuring. In his model, accumulating reserves has the benefit of improving lenders recovery rates after default, which implies a drop in sovereign spreads. Bianchi and Sosa-Padilla (2020) studies the accumulation of reserves in 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 unemployment in the future. Thus, the benefit of accumulating reserves is to provide 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 implicitly assuming coordination between the central bank and government.[9]

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

Other papers seeking to explain the demand for international reserves study the precautionary motive for reserve accumulation. Aizenman and Lee (2007) studies the accumulation of reserves in an open economy version of Diamond and Dybvig (1983), generating endogenous sudden stops. Caballero and Panageas (2008) shows that there are significant gains from having financial instruments that provide insurance against sudden stops. Durdu, Mendoza, and Terrones (2009) also models reserve accumulation as insurance against a sudden stop resulting from domestic shocks. Jeanne and Ranciere (2011) models reserves as an Arrow-Debreu security that pays off in a sudden stop, and provides a simple analytical formula to quantify the optimal amount of reserves. Calvo, Izquierdo, and Loo-Kung (2012) addresses the issue of 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) sheds 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) studies the accumulation of reserves in a model where the private sector can also accumulates a liquid foreign assets. They show that, although both private and central bank assets can serve as insurance against a sudden stop, only the central bank internalize the insurance role of reserves and, thus, accumulates international reserves. Cespedes and Chang (2020) studies the interaction between optimal foreign reserves accumulation and central bank international liquidity provision in a small open economy under financial stress. In their model, the benefit of accumulating reserves is to provide liquidity when financial frictions bind. Arce, Bengui, and Bianchi (2019) provides a macroprudential theory of reserve accumulation by showing that the government accumulates international reserves to reduce the exposure to sudden stops due to over-borrowing by the private sector. Arce, Bengui, and Bianchi (2019) 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 in private over-borrowing instead of government over-borrowing. In contrast to this strand of the literature, this paper not only endogenize a sudden stop but also the choice of public debt. Moreover, this is the first study shedding light on the role of central bank independence on reserve accumulation.

the lens of my model, and see how these motives for reserve accumulation are affected by the lack of coordination between policymakers.

A different strand of the literature analyzes the role of reserves implementing exchange rate policies. Obstfeld, Shambaugh, and Taylor (2009) documents that countries with a higher level of reserves in 2007 has less exchange rate depreciation during the crisis of 2008. Ghosh, Ostry, and Qureshi (2017) shows that emerging market central banks engage in foreign exchange intervention to smooth fluctuations in the real exchange rate, selling foreign reserves to prevent depreciation and buying reserves to prevent appreciation. Fratzscher et al. (2019) uses daily data on sterilized foreign exchange intervention to test if intervention has the desired effect on the exchange rate, finding that it does. Fanelli and Straub (2018) develops a theory of foreign exchange interventions in a small open economy with limited capital mobility. He shows that, in order to avoid excessive currency appreciation, the central bank accumulates reserves to lean against the wind of global capital flows. Cavallino (2019) studies foreign exchange interventions in a linear-quadratic New Keynesian model. In his model, the intervention is an additional tool to stabilize the economy in the presence of portfolio shocks. Amador et al. (2020) studies 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 an inflow of capital that the central bank needs to absorb by accumulating reserves. Davis, Devereux, and Yu (2020) studies how foreign exchange interventions can be used to prevent a sudden stop in a small open economy that faces exogenous shocks in its cost of borrowing. They show that reserve accumulation has two benefits: ex-ante by reducing the risk of a sudden stop and ex-post by limiting inefficient deleveraging. In contrast to this 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 in which there is a conflict of interest between policymakers and, for instance, one could think that this conflict could come from a disagreement between committing to a specific exchange rate policy or boosting the fiscal capacity of the government. 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 more independent central banks 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 calibration and presents the quantitative results. Section 6 concludes.

2 Facts on Reserves and Central Bank Independence

This section presents empirical evidence regarding the interaction between reserves and central bank independence. Subsection 2.1 describes the data sources used. Subsection 2.2 documents that more independent central banks tend to accumulate more international reserves. 2.3 provides anecdotal evidence that supports the main mechanism of the model.

2.1 Data

I use annual data from 1970 to 2017 for 11 Latin American countries. I focus on this region because the lack of fiscal discipline in Latin America is a well-documented fact. The appendix extends this analysis to a set of 30 emerging economies commonly used in the literature.[10] As it 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 sixteen criteria coded on a scale from 0 to 1 (lowest and highest independence, respectively) and reflects political independence, financial independence, and policy independence of the central bank 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.

[10]The full sample includes countries used in Alfaro and Kanczuk (2009) and Bianchi, Hatchondo, and Martinez (2018) that are classified as emerging economies by the IMF's World Economic Outlook. The 30 countries in the panel are Argentina, Bolivia, Brazil, Bulgaria, Chile, China, Colombia, Croatia, Ecuador, Egypt, Hungary, India, Indonesia, Lebanon, Malaysia, Mexico, Morocco, Pakistan, Paraguay, Peru, Philippines, Poland, Romania, Russia, Saudi Arabia, Thailand, Turkey, Ukraine, Uruguay, and Venezuela.

2.2 International Reserves and Central Bank Independence

Motivated by a terrible history dealing with high inflation rates, and inspired by Rogoff's view of delegating monetary policy to a "conservative central banker", 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.[11] While the negative correlation between CBI and inflation is a well-established fact[12], the effect of CBI on the accumulation of foreign assets held by central banks has not been studied. To the best of my knowledge, this is the first paper that documents a positive correlation between central bank independence and the accumulation of international reserves.

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

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

where α_i represents time invariant country fixed effects and γ_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 explanatory variables are lagged one period to control for endogeneity. $(CBI)_{i,t}$ 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 the variables considered in the theoretical model except for sovereign spreads.[13]

Table 1 reports results for the 11 Latin American countries in the sample. The analysis shows that, other things equal, the positive correlation between CBI and the accumulation of reserves 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. Specification (4) controls by inflation rate, exchange rate regime, and sovereign spreads.

[11] See Rogoff (1985), Waller (1992), Walsh (1995), and Svensson (1997). Walsh (2003) emphasizes two key aspects of independence: insulation from politics when it comes to defining the objectives of monetary policy, and the independence to freely implement policy once those goals have been defined.

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

[13] 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.

The coefficient associated with the inflation rate is negative, which is consistent with previous studies such as Alesina and Summers (1993) and Walsh (2008). To control for exchange rate regime, I introduce a dummy variable that assigns "0" to countries with flexible exchange rates and "1" to countries with fixed exchange rates.[14] 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, I include sovereign spreads as a control variable. The coefficient associated with spreads is negative, which is consistent with the model. In summary, this subsection documents that more independent central banks tend to accumulate more international reserves.

Table 1: Panel Regressions

	Dependent variable: $log(A/y)$			
	(1)	(2)	(3)	(4)
CBI	**2.36****	**2.38****	**2.37****	**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

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

[14] I use the fine classification codes from Ilzetzki, Reinhart, and Rogoff (2017). I assign a "0" to those countries classified from "1" to "8" in IRR, and "1" to those countries classified from "9" to "14" in IRR.

2.3 Supportive Anecdotal Evidence

This subsection provided anecdotal evidence that supports two key assumptions of the model: (i) the conflict of interest between the central bank and government, and (ii) the central bank's capability to retain its reserves when the government defaults.

Conflict of Interest.—The case of Argentina illustrates pretty well not only the conflict of interest among policymakers but also the importance of having an institutional framework that insulate the central bank from political pressures. In 2010, the President Cristina Fernandez de Kirchner announced a plan to use international reserves to pay back debt. However, the central bank president refused to support her plan. According to the *New York Times*, M̈rs. Kirchner's cash-poor government is seeking to use $6.5 billion of Argentina's nearly $48 billion in central bank reserves to help cover $13 billion in international debt... But after her central bank president, Martin Redrado, refused to support the plan, Mrs. Kirchner fired him by decree on Thursday. On day later a federal judge, Maria Jose Sarmiento, blocked Mrs. Kirchner's plan to tap the reserves and ordered Mr. Redrado reinstated, saying that only Congress could remove him."[15] In the case of Mexico, politicians have also manifested an interest to use the reserves held by the central bank. For instance, in 2018 the Mexican congressman Benjamin Robles Montoya proposed to use the international reserves to finance public investment and anti-poverty programs.[16]

Reserves after Default.—Argentina is also a good example of the central bank's capability to retain its reserves when a default episode occurs. In 2015, the Argentinian central bank won the reversal of a U.S. court ruling that had allowed bondholders to try to hold it responsible for the debt 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 bank's assets."[17]. This case sets an international precedent and guarantees that vulture funds will not be allowed to seize the central bank assets when a government defaults.

[15] Argentine President and Central Bank in Standoff, *New York Times*, January 10, 2010.
[16] Proponen utilizar reservas internacionales en inversion productiva, El Sol de Mexico, October 31, 2018.
[17] U.S. appeals court says bondholders cannot seize Argentina's reserves, *Reuters*, August 31, 2015.

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 government behaves as a consolidated entity.

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

$$\mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t u(c_t) \right\}, \tag{1}$$

where $\mathbb{E}$ denotes the expectation operator conditional on information at time 0, 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 constant over time and sufficiently large to finance the accumulation of reserves.[18]

[18] In the absence of money, the central bank does not have any endogenous income to finance the accumulation of reserves. By allowing an exogenous inflation tax, I introduce a source of income for the central bank in the simplest way. Alternatively, I can assume fiscal support as most of the related literature implicitly does. However, in any case the resource constraint of the economy is the same and the results do not change substantially.

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

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

where β^F and β^M denote the discount factors of the government and the central bank, respectively. In particular, I assume that the government is more impatient relative to the central bank to capture the idea that the central bank can be isolated from political pressures through its independence, i.e., $\beta^F < \beta^M = \beta$. This assumption, which is key for most results in this paper, is the main departure from the sovereign default literature studying the joint accumulation of reserves and debt.

Previous studies assume a consolidated government, with a high degree of impatience, that chooses simultaneously reserves and debt. 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 low discount factor for the government, this may not be accurate for an independent central bank. As discussed in section 2, independent central banks operate in institutional frameworks that isolate them from political pressures and that align the central banks' incentives with those of the household.[19]

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 assume that τ^π is sufficiently large to finance the accumulation of international reserves, and the central bank can also transfer resources to the government, $\Omega \in \Re_{++}$.[20] Therefore, the central bank's budget constraint is given by

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

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

[20]In practice, central banks transfer their surplus annually to the government (In the case of the Mexican central bank, these funds are called "Remanente de Operaciones"). However, most central banks can also transfer resources indirectly by buying government bonds. In the model, I abstract from this distinction and consider any form of transfer from the central bank to the government.

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.

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. Finally, the government also receives transfers from the central bank that can be used either to transfer resources to the households or to pay previous liabilities. 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).[21] 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 section 2, I also 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).

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

Therefore, the resource constraint during default is given by

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

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 bond's 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.[22] 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.[23] 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. [24]

Conflict of Interest 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 improve the foreign net position of the economy as a whole.

[22]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).

[23]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.

[24]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.

Since policymakers have different policy instruments to affect the net debt position of the economy, defined as $N \equiv B - A$, this disagreement among policymakers could be illustrated by rewriting the resource constraint—eq. (5)—as follows

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

The third term of the RHS, $q_t B_{t+1}$, illustrates that the government can front-load consumption by issuing debt, and the forth term of the RHS, $q^* A_{t+1}$, illustrates that by accumulating reserves the central bank can reduce consumption today to improve the foreign net position. 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 5.4 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}.
3. Households consume, c_t.

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:

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

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

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

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 5.4 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. (15).
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 disagreement 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 a 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.

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 shows that the baseline model rationalizes positive levels of reserves and debt. Proposition 4 characterize the optimal allocations of debt and reserves. 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 the same rate as households and the rest of the world. This assumption let me characterize analytically 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* $t \geq \bar{t}$*.*

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 2 illustrates that, in this specific example, the government consume 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 *(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.

Proposition 3 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 conflict of interest 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 3 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 conflict of interest, as well as the different policy tools that policymakers have to affect the net debt position, leads to a simultaneous game where the government uses debt markets to front-load consumption and the central bank accumulates reserves to smooth consumption. Figure 4 illustrates policymakers' best responses for a given initial levels of debt and reserves. 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 for any level of reserves.

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 there is no borrowing limit. However, these two assumptions imply a spread on interest rates that makes costly for the government to undo the effect of reserve accumulation by issuing more debt. Subsection 5.4 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.

Proposition 4 *(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.

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

Proof. See appendix.

Proposition 4 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. Moreover, corollary 1 tell us that an independent central bank can implement the optimal net debt position of the economy by accumulating international reserves. Figure 5 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 not longer true in the stochastic environment because the default risk implies a spread on interest rates, subsection 5.5 shows that accumulating reserves is still welfare improving.

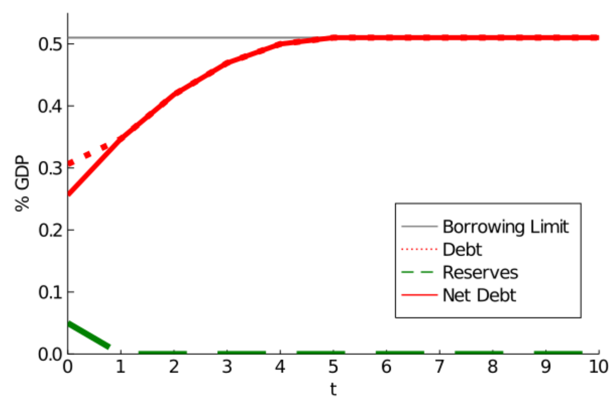


Figure 2: Consolidated Government Equilibria

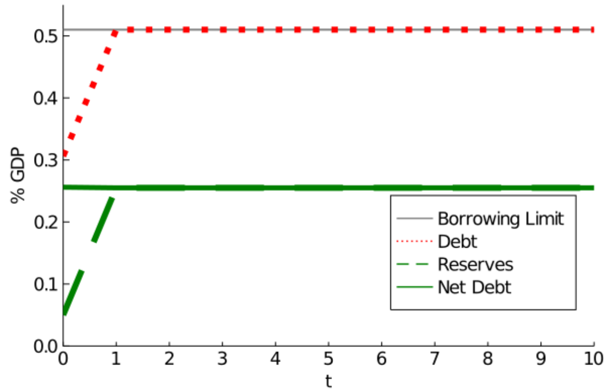


Figure 3: Two-Government-Entities Equilibria

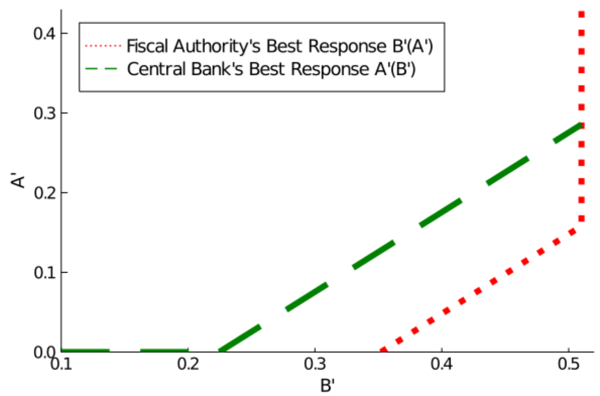


Figure 4: Government Entities' Best Responses

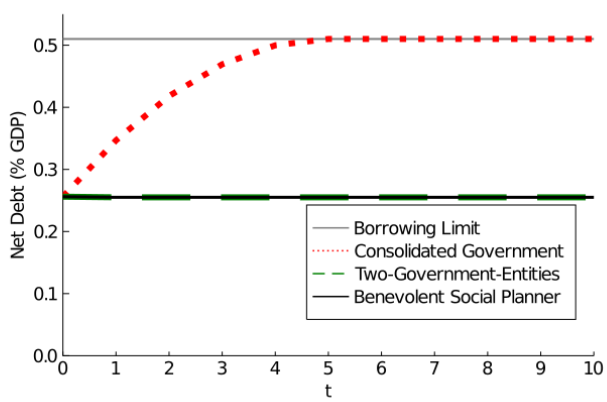


Figure 5: Optimal Net Debt

5 Quantitative Analysis

In this section, I present the quantitative analysis of the model. Subsection 5.1 describes the computation of the model. Subsection 5.2 presents the calibration. Subsection 5.3 presents key statistics in the data and in the model simulations. Subsection 5.4 inspects the mechanism of the model. Subsection 5.5 explores the welfare implications of having an independent central bank that can accumulate international reserves.

5.1 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.

5.2 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. 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.[25] 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.[26] With this procedure, I obtain 3 episodes of high risk premium every 20 years with an average duration equal to 1.25 years, which implies $\pi_{LH} = 0.15$ and $\pi_{HL} = 0.8$.[27] 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 that Mexico was excluded

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

[26]I use quaterly data from 1993 to 2017, excluding data for sovereign default episodes following Catao and Mano (2017).

[27]The high risk premium episodes are observed in 1994-1995 (Tequila crisis). 1998 (Russian default), and 2008 (global financial crisis). On average, the global EMBI+ was 2 percentage points higher in those episodes than in normal periods.

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 $\beta^M = 0.966$.

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	0.15	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	0.946	Debt to GDP = 44.4%
d_0	Default cost parameter	-0.081	Average spread = 273 bp
d_1	Default cost parameter	0.902	Increase in spread = 300 bp
κ_H	Pricing kernel parameter	0.17	corr $(r_s, B/y) = -0.1$

There are four parameters calibrated by simulation: the government's discount factor β^F, the parameters associated to 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 300 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 low correlation between public debt and GDP. The government's discount factor mainly determine 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 correlation between debt and GDP.

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.[28] 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.[29] While there is no a perfect way to solve this trade-off, I choose to target total public debt because it is the most general instrument that approximates the behavior of the government. The online appendix presents an alternative calibration where the government's discount factor is calibrated to match the debt service.

5.3 Key Statistics: Model vs Data

Now, I report long-run moments in the data and in the model simulations.[30] 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 7.2%, which corresponds to 83% 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 the data, as well as the pro-cyclical behavior of

[28]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.

[29]Currently, I am enhancing the baseline model by adding long-term debt as in Bianchi, Hatchondo, and Martinez (2018).

[30]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.

reserves. Most of these results are consistent with Bianchi, Hatchondo, and Martinez (2018).[31]

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 economies documented by Bianchi, Hatchondo, and Martinez (2018). Finally, the model underestimates the historical probability of default.[32] However, the model was calibrated for the period where the central bank has been independent and there are not default episodes observed in this period.

Table 4: Targeted Moments

	Data	Model
mean B/y (%)	44.4	43.3
mean r_s (%)	2.7	2.7
Δ (r_s) for $\kappa = \kappa_H$ (%)	3.0	2.9
corr $(B/y, y)$	-0.1	0.0

Table 5: Non-targeted Moments

	Data	Model
mean $(\mathbf{A/y})$ (%)	**8.7**	**7.2**
corr $(A/y, B/y)$	0.6	0.8
corr $(A/y, y)$	0.7	0.3
corr (c, y)	0.8	0.9
std (r_s) (%)	1.3	3.0
default prob (%)	3.0	0.9

[31] 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.

[32] According to Catao and Mano (2017), the Mexican government has defaulted on its debt 3 times in the last 100 years, which gives a rough estimate for the historical default probability of 3%.

5.4 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 household's intertemporal consumption. This disagreement can be illustrated be considering two economies where reserves and debt are chosen by the same policymaker. Let $\bar{A}^F(y,\kappa,B,A)$ and $\bar{B}^F(y,\kappa,B,A)$ 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),

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

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

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

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

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

Figure 6 illustrates the disagreement among 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 among policymakers is represented by the difference in consumption. Panel (b) illustrates that the disagreement about intertemporal consumption implies a conflict of interest about the net debt position of the economy, where the government would choose to issue more debt than what is socially optimal. For this specific state, government's overborrowing is equivalent to the disagreement about intertemporal consumption and equal to 6% of GDP.

In the baseline model, policymakers not only disagree about the 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 to buy one risk-free asset the central bank has to pay q^* units of consumption today, 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 7a 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 change substantially the incentives to default for the government, thus the bond price schedule is almost flat on the accumulation of reserves. Figure 7b 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

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

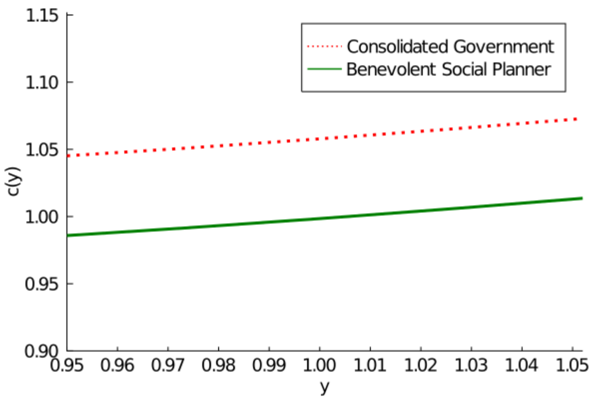
which implies that by issuing one more bond the government delivers q^* units of consumption and, vice versa, the central bank transfers one unit of consumption from today to tomorrow by buying one bond at price q^*. This is,

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

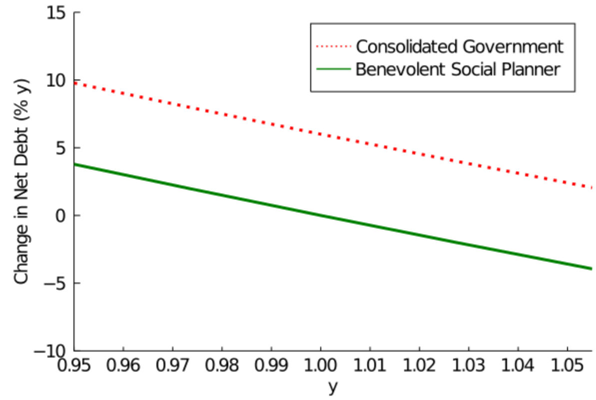
Therefore, the spread on interest rates, $r_s = \frac{1}{q} - \frac{1}{q^*}$, is key to undo government borrowing because it increases the cost of holding portfolios with high levels of reserves and debt.

Figure 8 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.

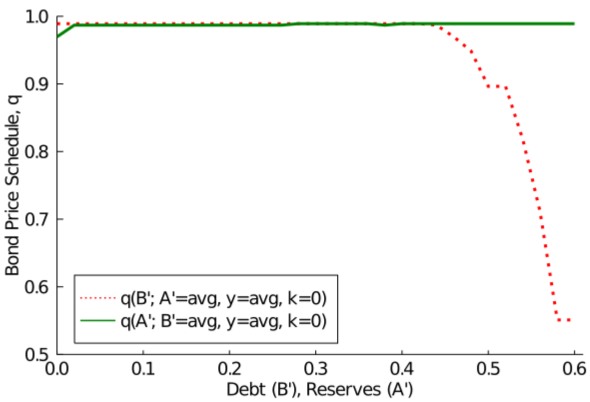


(a) Difference in Consumption

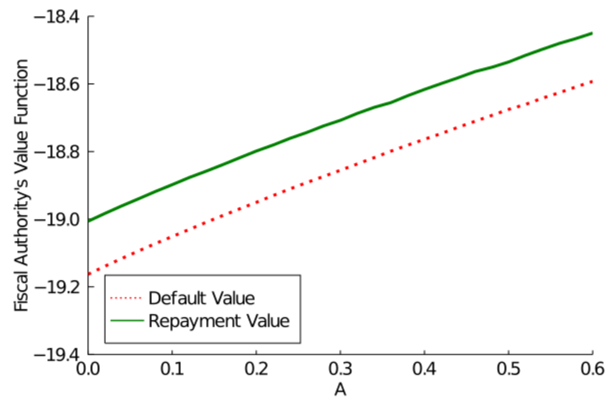


(b) Difference in Net Debt

Figure 6: Conflict of Interest among Policymakers

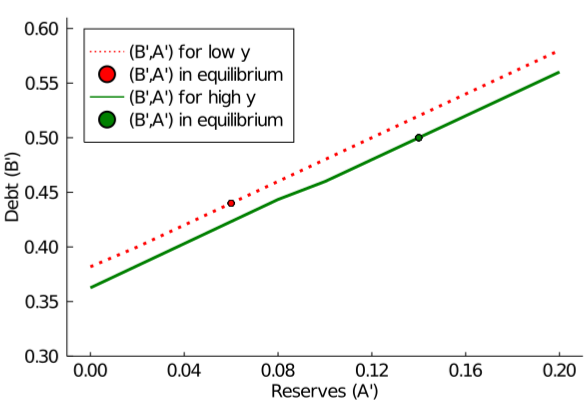


(a) Bond Price Schedule

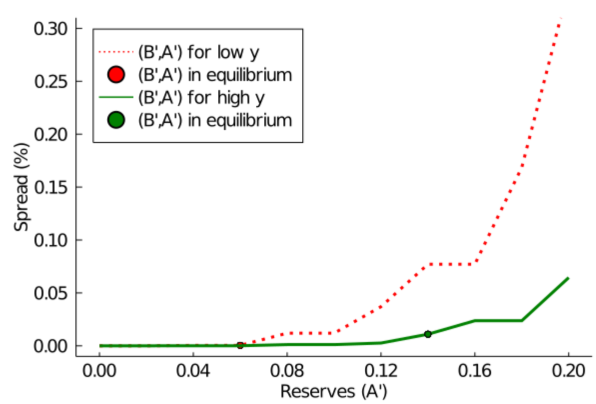


(b) Government's Value Function

Figure 7: International Reserves and Sovereign Risk



(a) Portfolios of Reserves and Debt



(b) Cost of Accumulating Reserves

Figure 8: Reserves and Debt Choicesl

5.5 Welfare Analysis

Now, I explore the question of whether accumulating reserves is welfare improving. On one hand, the central bank accumulates reserves to undo government borrowing. On the other hand, this is costly because using reserves to pay back debt reduces sovereign spreads. To quantify the welfare gains of accumulating reserves, I contrast the baseline model with a consolidated government economy. Table 6 shows that, when the central bank is as impatient as the government (i.e. not independent central bank), the model is consistent with Alfaro and Kanczuk (2009).

Table 6: Independent Central Bank vs Consolidated Government

	Independent CB	Consolidated
mean B/y (%)	43.3	39.4
mean A/y (%)	7.2	0.0
net debt position (%)	36.1	39.4
change in welfare (%)	**0.1**	**0.0**

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

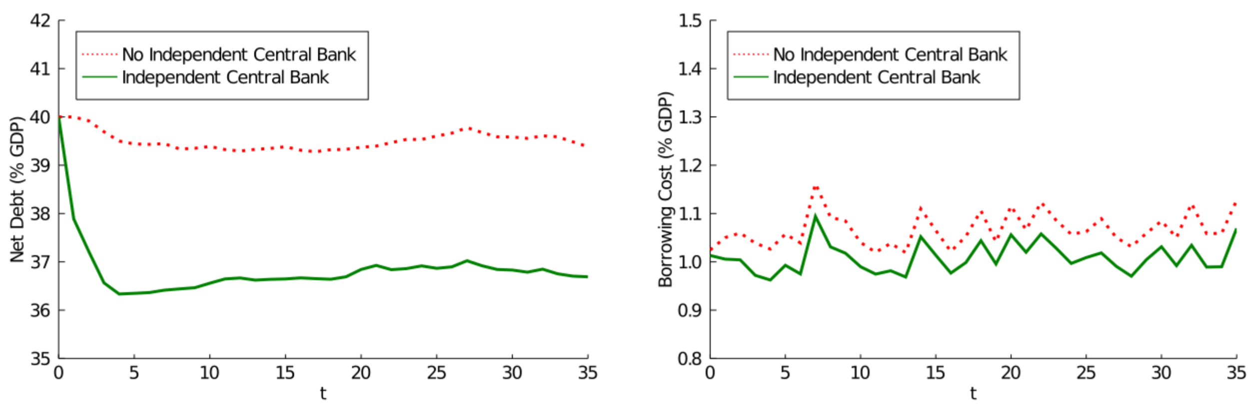
$$V_{NoInd}(C,\lambda) = E\left[\sum_{t=1}^{\infty}\beta^{t-1}u((1+\lambda)c_t^{NoInd})\right] \approx \sum_{t=1}^{T}\frac{1}{N}\sum_{n=1}^{N}\beta^{t-1}u((1+\lambda)c_{t,n}^{NoInd}),$$

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 $\lambda^* = 0.0008$. Thus, having an independent central bank that can accumulate reserves to offset government borrowing increases social welfare by 0.1%. Figure 9 illustrates where are the welfare gains coming from. Panel (a) illustrates that by accumulating reserves, the central bank reduces the net debt position by 3.3% of GDP. Panel (b) shows that the borrowing cost, defined as the net debt position multiplied by the spread on interest rates, $r_s N$, goes down when the central bank is independent.



(a) Fiscal Authority's Over-borrowing

(b) Borrowing Cost

Figure 9: Welfare Gains

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 reserves held by an independent central bank cannot be appropriate 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 towards the future in a way that cannot be undone by a government that lacks fiscal discipline. Quantitatively, my central bank independence channel accounts for 83% of the average level of reserves observed in Mexico from 1994 to 2017, a period during which the Mexican central bank has been independent.

Overall, this paper provides a tractable framework to study the joint dynamics of international reserves, public debt, and sovereign spreads without assuming coordination between the central bank and the government. I believe an interesting avenue for future research may be to introduce the hedging motive in Bianchi, Hatchondo, and Martinez (2018), and further study the variance decomposition of the level of international reserves.

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