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Default and Interest Rate Shocks: Renegotiation Matters*

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Abstract

We develop a sovereign default model with debt renegotiation in which interest-rate shocks affect default incentives through two mechanisms. Under the standard mechanism, higher interest rates tighten the government's budget constraint. Under the renegotiation mechanism, higher rates increase lenders' opportunity cost of holding delinquent debt, which makes lenders accept larger haircuts and makes default more attractive for the government. We argue that our novel renegotiation mechanism reconciles standard sovereign default models with the narrative that the sharp increase in the real interest rate in the United States was a relevant factor in the defaults of the early 1980s.

Keywords: Sovereign default, Renegotiation, Interest rate shocks

JEL Codes: F34, F41, G28

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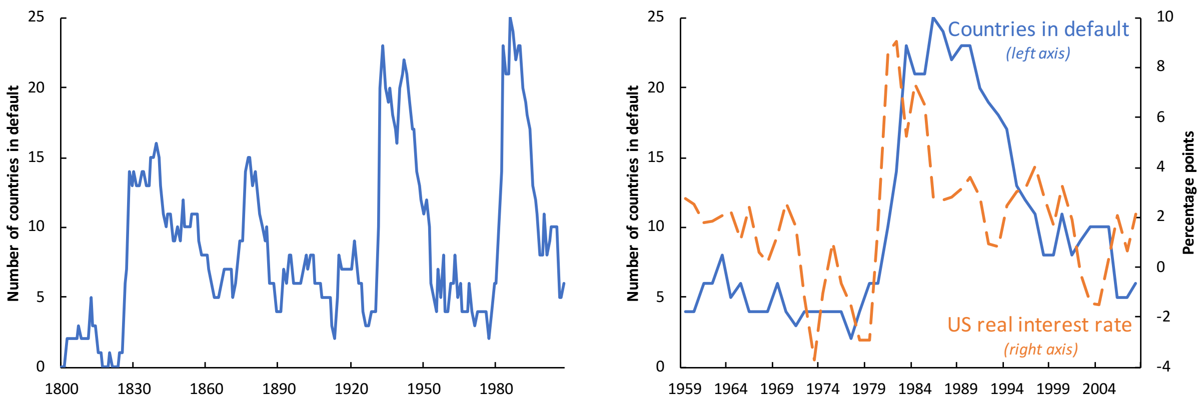
1 Introduction

The 1980s featured the most widespread sovereign debt crisis in history. The left panel of Figure 1 shows how it compares with other stressful periods in sovereign debt markets, such as the Napoleonic Wars, World Wars I and II, and the Great Depression. Mexico was the first country to default in August 1982, and by 1985, the crisis reached a peak of 25 countries suspending some or all debt payments.



(a) Sovereign defaults in historical perspective (b) Co-movement of defaults and interest rates

Figure 1: Sovereign defaults and U.S. real interest rates

Note: The U.S. real interest rate is the annual yield on 1-year U.S. treasury bonds minus observed inflation.

Source: The data of countries in default are from Reinhart and Rogoff (2009). The data for the U.S. real interest rate were retrieved from FRED, Federal Reserve Bank of St. Louis.

The crisis was preceded by aggressive interest rate increases in the United States that were the result of policies implemented by the Federal Reserve, chaired by Paul Volcker, with the purpose of taming rising inflation. The right panel of Figure 1 shows how real interest rates in the U.S. were a leading indicator of the number of countries in default during the 1980s: shortly after the initial rate hike, there is a cascade of sovereign defaults.

This "Volcker shock" is often credited as the trigger of the crisis. The usual narrative focuses on the direct impact that higher interest rates had on debt service, since most debt had been contracted at floating rates (see, for example, Ocampo (2014) and Tourre (2017)). According to this narrative, an increase in the risk-free rate increases all rates, which makes servicing current debt more expensive, which in turn makes default more attractive. We refer to this as the *standard mechanism*.

We argue that the same interest rate shock has an additional indirect effect on default incentives through the terms that government expects to emerge from an eventual debt renegotiation. We refer to this as the *renegotiation mechanism*. To demonstrate the workings of our mechanism, we introduce persistent shocks to the risk-free interest rate and debt renegotiation through Nash bargaining into a standard model of sovereign default by a small open economy. We show that, when the risk-free interest rate is high, renegotiation following a default gives the government a more favorable outcome in the sense that it leads to a larger haircut than when the risk-free rate is low. The intuition for our mechanism is simple: lenders' opportunity cost of holding delinquent debt is high when the risk-free rate is high, so they are willing to accept a lower recovery rate on the debt for payments to resume. This renegotiation mechanism is quantitatively appealing because it provides an endogenous force relating high interest rates with small default penalties, which is crucial in generating realistic default frequencies with quantitative sovereign default models.

Our numerical exploration is first done with a model calibrated to Mexico in the early 1980s. We use data before 1982 to calibrate the parameters in a standard manner. Importantly, we calibrate the parameters that govern the bargaining game so that the average haircut generated by the model equals the haircut to Mexican debt under the Brady Plan in 1990. We find that, in the ergodic distribution, 21 percent of interest rate hikes calibrated to match the Volcker shock trigger a default event. To compare the relevance of the renegotiation mechanism with that of the standard mechanism, we consider two counterfactual economies that feature a fixed debt haircut instead of endogenous renegotiation. For the first, we consider a haircut of 100 percent, which is akin to canonical models in the literature in which governments are readmitted to financial markets with no debt (see Aguiar and Gopinath (2006), Arellano (2008), Chatterjee and Eyigungor (2012)). For the second, we consider a fixed haircut equal to the average targeted in our benchmark calibration. In these two counterfactual economies, the fraction of interest rate hikes that trigger a default event is 5 percent in the first economy and 12 percent in the second. We draw two conclusions from these quantitative exercises. The first is that without the possibility of some debt recovery, interest rate hikes have a small effect on default incentives. This implies that the usual narrative of the Volcker shock triggering the Mexican default in 1982 solely through higher interest costs is unlikely. Our second conclusion is that in the presence of some debt recovery after default, the renegotiation mechanism described above accounts for roughly half of the default risk generated by interest rate hikes.

In the model we study, following default, there is an exogenous and constant Poisson probability of a renegotiation occurring in each period. Our benchmark calibration follows the standard practice of using average default duration in the data. The default episodes of the 1980s were particularly long, and we use a probability that implies an average waiting time of over five years. This benchmark calibration produces the results summarized above.

But there are reasons to doubt the validity of this standard calibration strategy. The protracted period of renegotiations that characterized the default episodes of the 1980s was, to a large extent, a consequence of interference by U.S. bank regulators, who were concerned about the health of the U.S. banking system. A justification for their concern was that the total debt in default amounted to a large share of the capital of some of the large U.S. banks, which had been heavily involved in lending to sovereigns, especially in Latin America, during the 1970s. U.S. bank regulators feared that any renegotiation that included substantial haircuts of the debt of Latin American countries that followed it into default would cause a banking crisis in the United States.

By 1989, after these banks had time to recapitalize, the U.S. government set up the Brady Plan, which allowed the banks to convert this debt into different types of dollar-denominated bonds, all of which included some form of a haircut, that could be freely traded. The Brady Plan was complex, entailing negotiations led by the U.S. government that involved the governments of the countries in default, the IMF, and the World Bank. What is important about the Brady Plan for our analysis is that it was not the sort of bilateral negotiation between the governments and its U.S. bank creditors that could have been anticipated in 1982.

The main focus of the paper is the renegotiation mechanism and its role in Latin American governments' decision to default. From the point of view of this paper, therefore, what is important is that although it took the Mexican government eight years to successfully renegotiate its debt, by which point the Volcker shock had ended, it is natural to consider the case in which in 1982, Mexican authorities imagined that they could renegotiate their sovereign debt faster than what our benchmark calibration implies. We show that our quantitative results are indeed sensitive to the specific value we assume for the renegotiation probability. If, for example, we assume that from default experiences in the 1970s, the Mexican government expected to be able to renegotiate once every two years on average, then the probability of a Volcker shock triggering a default in the standard model with no recovery value goes from 5 percent to just 7 percent. In contrast, with a fixed haircut, it goes from 12 percent to 25 percent, while with an endogenous haircut, it goes from 21 percent to 41 percent. Overall, our results imply that endogenous renegotiation is a key factor in understanding the effect of risk-free shocks on default decisions.

We also analyze a very large number of simulated economies. Each simulated economy is randomly drawn for a wide set of parameter values. This exercise confirms that the quantitative relevance of the renegotiation mechanism, which is the focus of the paper, does not depend on the particular calibration for Mexico.

As additional evidence, we exploit existing data to test the main mechanism, using independent reduced-form statistical methods. Specifically, we look for evidence relating a high risk-free rate during renegotiation with more favorable terms for a government that has defaulted. To do this, we use the data and the empirical methodology of Asonuma, Niepelt and Ranciere (2023), who study sovereign default and renegotiation episodes during the period 1999–2020. We find significant evidence for the renegotiation mechanism. In particular, we find that a risk-free rate that is 1 percentage point higher during a successful renegotiation of debt after a default is associated with a haircut that is between 6 and 7 percentage points higher.

The model that we employ in this paper is based on the theoretical work of Eaton and Gersovitz (1981): Hamann (2002), Aguiar and Gopinath (2006), Arellano (2008), Hatchondo and Martinez (2009), and Chatterjee and Eyigungor (2012). It is closely related to the literature on debt renegotiation in quantitative sovereign default models. Yue (2010) develops a model with debt renegotiation with Nash bargaining after a default. There are two major differences between Yue's analysis and ours. First, she does not study interest rate shocks. Second, she makes different assumptions about the outside options in the renegotiation game, which make our renegotiation mechanism inoperative. Yue assumes that if renegotiation is unsuccessful, then the government remains in autarky forever, and the lenders recover nothing. In contrast, we assume that if renegotiation is unsuccessful, then the government and lenders have to wait for the next renegotiation opportunity to bargain again. With this assumption, the outside option of the lenders is dependent on the risk-free interest rate in the renegotiation period, which is crucial to the renegotiation mechanism.

In related research, Benjamin and Wright (2009), Pitchford and Wright (2012), Bai and Zhang (2012), Benjamin and Wright (2019), and Asonuma and Joo (2020) develop sovereign default models in which delays in renegotiation arise endogenously as strategies in the bargaining game to restructure debt. Similarly, Dvorkin et al. (2021) study sovereign debt renegotiation in a model in which governments and lenders make alternating offers and endogenous delays are possible through taste shocks that are realized after these offers have been made. A key difference between our model and theirs is that once there is an opportunity for renegotiation in our model, our assumptions prevent delays from happening in equilibrium. What is essential for our results is the threat of delay.

There is also literature on debt renegotiation before a default. Hatchondo, Martinez and Sosa Padilla (2014) develop a model of voluntary debt exchanges in which the government and lenders can choose to reduce the value of the debt before a default occurs. These exchanges are mutually beneficial and happen in equilibrium when the stock of debt is to the right side of the Laffer curve. Unlike them, we do not allow for debt renegotiation to prevent a default in our model. Asonuma and Trebesch (2016) document that roughly 38 percent of debt restructurings happen preemptively, have lower haircuts, and are quicker to negotiate. We choose to focus on ex-post restructuring out of simplicity and because that is what happened after the Latin American defaults. The two mechanisms that we identify would be also present in any model of restructuring that occurs ex-ante.

Mihalache (2020) documents that debt relief programs are often implemented through maturity extensions, rather than through reductions to the face value of debt. We hypothesize that the essence of our results would not change if maturity extensions were included in the renegotiation game. We expect that our main result, that the government would receive a more favorable outcome from renegotiation with high interest rates, would still hold, whether that outcome takes the form of a higher debt haircut or a more convenient maturity extension. This is obviously a topic that merits more research.

It is worth pointing out that we are not the first researchers to point out that the standard mechanism by itself does not provide much of a role for interest-rate shocks to affect a government's default decision in a standard quantitative model of sovereign debt and default. Johri, Khan and Sosa-Padilla (2022), Tourre (2017), and Singh (2020) make similar points (although the analysis that establishes this point is not included in the published version of Johri, Khan and Sosa-Padilla (2022)).

Guimaraes (2011) asks a question similar to ours: In a model with a small open economy where there are shocks to both income and the world interest rate and default is settled through renegotiation, which type of shock has a larger impact on haircuts? Guimaraes argues that interest rate shocks play a larger role than income shocks. These results are complementary to ours. It is difficult to compare the two papers, however, because his is analytical while ours is quantitative, and his modeling of default and renegotiation is very different from ours. He assumes that if a country has trouble repaying a fixed debt obligation, it asks its creditors for immediate renegotiation. In this renegotiation, the debt obligation is cut to the maximum amount that satisfies the country's incentive compatibility constraint. This feature makes his model more like those of Alvarez and Jermann (2000) and Kehoe and Perri (2004), which have complete contingent claims markets and enforcement constraints like those in the debt constrained asset markets of Kehoe and Levine (1993, 2001). Perhaps the papers in the sovereign debt literature most closely related to Guimaraes (2011) are Hatchondo, Martinez and Sosa Padilla (2014), which studies renegotiation before a costly default can occur, and Roch and Roldán (2023), which studies state contingent bonds that pay off only if the country meets a specified performance level, such as a growth of real GDP target.

The paper proceeds as follows. In Section 2 we present the reduced form evidence. Section 3 presents a simple model of sovereign default and renegotiation that allows for a theoretical characterization of the standard mechanism and the renegotiation mechanism, and provides an intuition for our main result. Section 4 presents the general model and the quantitative experiments with the benchmark calibration. We also briefly discuss a narrative of the default episodes of the early 80s, their effect on the balance sheets of U.S. banks, and the debate it created among U.S. policymakers and regulators. We use this narrative to hypothesize that officials in the Mexican government in August 1982 likely expected a much shorter delay in renegotiation. We test the importance of this hypothesis by redoing our quantitative experiment with a higher probability of renegotiation and show that our negotiation mechanism is much stronger in our model. Then, in Section 5, we present the analysis of a large number of simulations of the model with random parameters. Section 6 concludes.

2 Evidence

To motivate the main mechanism implied by the renegotiation game, we first present a simple statistical exploration of the relationship between the risk-free rate and the resulting haircut in a debt renegotiation.

We use the dataset constructed by Asonuma, Niepelt and Ranciere (2023), who compute haircut measures for different sovereign debt instruments in various restructuring episodes. Following Sturzenegger and Zettelmeyer (2008), the haircut for a debt instrument i exchanged for another instrument e (hereafter, SZ haircut) is

$$h_{i,e}^{SZ} = 1 - \frac{NPV\,(r_e, x_e)}{NPV\,(r_e, x_i)}, \tag{1}$$

where $NPV\,(r, x)$ is the net present value of the cash flow stream of a debt instrument discounted at a rate r and x is a vector of the instrument's face value, maturity, and coupon structure. A key detail is that both streams are discounted at the exit yield of the new instrument r_e, which reflects the creditor's new repayment capacity moving forward. Thus, the haircut defined in (1) captures the actual loss to investors of the new characteristics x_e, relative to a benchmark with the old characteristics x_i, under the new economic conditions captured by r_e.

The data of SZ haircuts from Asonuma, Niepelt and Ranciere (2023) are for 531 instruments from 44 restructurings. We focus strictly on restructurings that happen after default, like the ones in our model. Our sample features 139 instruments in 17 episodes. Figure 2 shows the relationship between haircuts in these 17 episodes and the real risk-free interest rate at the month of restructuring (described below). The dots are the average haircut in each episode, and the vertical bars indicate one standard deviation around them. The labels show the defaulting country and the month of restructuring.

The episodes in Figure 2 span through the entire period studied by Asonuma, Niepelt and Ranciere (2023) and show a positive relationship between haircuts and the prevailing risk-free rate at the time of restructuring, which is a key prediction of our model. Particularly interesting are the restructurings of Ecuador and of Antigua and Barbuda around the global financial crisis in 2009. Ecuador restructured in June under relatively high interest rates and got an average haircut of 65 percent, while Antigua and Barbuda restructured in December, once interest rates were very

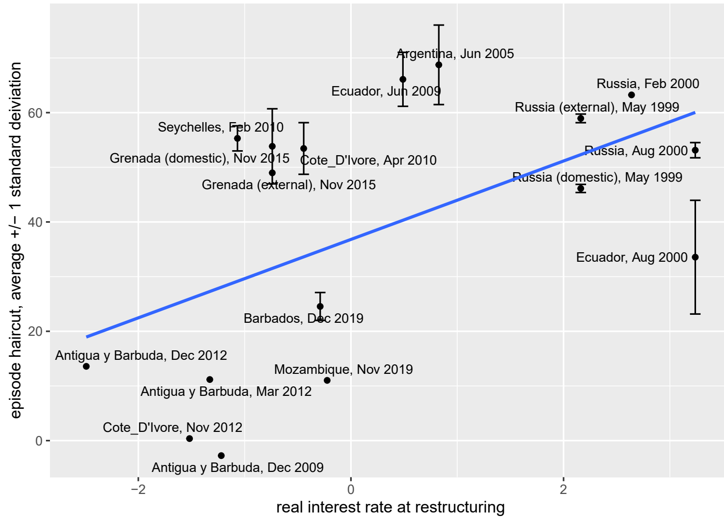


Figure 2: Haircuts and interest rates

Note: The dots are the average haircut in each episode, and the vertical bars indicate one standard deviation around the mean. The labels show the defaulting country and the month of restructuring.

Source: The haircut data are from Asonuma, Niepelt and Ranciere (2023). The real interest rate is the annual yield on 1-year U.S. treasury bonds minus observed inflation retrieved from FRED, Federal Reserve Bank of St. Louis.

low, and got a negative haircut. Interest rates, of course, are not the only determinant of the size of haircuts, and the vertical bars show that there is additional variation even within episodes that cannot be attributed to the risk-free rate or to country-specific characteristics. Following the analysis in Asonuma, Niepelt and Ranciere (2023), we estimate the following regression:

$$h^{SZ}_{i,e,j,t} = \alpha + \beta r_t + \Gamma C_{i,e} + u_j + \epsilon_{i,e,j,t}, \tag{2}$$

where $h^{SZ}_{i,e,j,t}$ is the SZ haircut to instrument i exchanged for instrument e during episode j at date t, r_t is the 1-year U.S. real interest rate at date t (we use monthly values, since the data include the exact date of the exchange), u_j is a random effect for episode j, $\epsilon_{i,e,j,t}$ is the error term, and $C_{i,e}$ is a vector of relevant controls considered by Asonuma, Niepelt and Ranciere (2023): the remaining time to maturity at the time of the exchange, the coupon rate of instrument e if it is fixed, and an indicator variable on whether e has a floating coupon rate.

As Table 1 shows, the coefficient on the real risk-free interest rate is positive and significantly different from 0. Column (1) reports the OLS estimation of the average haircut in each episode on the risk-free rate, and Column (2) reports the random-effects estimation of equation (2). The estimated coefficient implies that each additional percentage point in risk-free rates increases haircuts by between 6 and 7 percentage points.

Table 1: Regression results

	SZ haircuts	
	(1)	(2)
real risk-free rate	7.17	6.30
	(2.54)	(2.92)
maturity of instrument (years)		-0.22
		(0.12)
coupon rate (fixed, percent)		1.08
		(0.41)
coupon rate (float, dummy)		2.08
		(4.52)
constant	36.81	35.26
	(5.34)	(6.72)
Observations	17	79
Random effects	No	Yes

Note: Robust standard errors in parentheses.

This result is robust to controlling for subsets of the relevant variables studied by Asonuma, Niepelt and Ranciere (2023). (The Appendix provides additional robustness analyses.) Table 1 provides support for the theoretical mechanism implied by the model.

3 A simple theoretical model

In this section, we solve a simple model of sovereign default. The main innovation is to explicitly model the renegotiation game following default and show how outcomes depend on the risk-free rate. The purpose is to characterize the properties of the renegotiation mechanism that is at the heart of the paper.

An impatient government faces a stochastic stream of income and issues short-term defaultable debt. Every period, the government can decide to default or repay. In case of default, the government is in financial autarky for a stochastic number of periods and suffers an income loss during exclusion. Income is fixed at a value lower than its average, and there are no payments made to the lenders.

During exclusion, opportunities to negotiate a jointly beneficial agreement arrive with some exogenous, time-invariant probability. The object of renegotiation is the size of constant and permanent coupon the government will pay the lenders forever. Upon a successful renegotiation, the government receives a constant flow of income that is higher than the value during exclusion. We assume the country can commit to pay the negotiated coupon after a renegotiation. This makes the problem essentially static after the renegotiation. Figure 3 illustrates the evolution of income over time throughout the game.

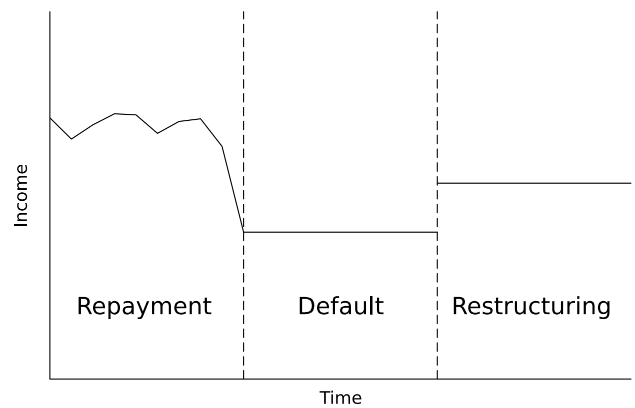


Figure 3: Income throughout the game

Notice that once an agreement has been reached, the allocation is stationary and easy to solve. This allows us to solve for the equilibrium using backward induction and obtain some enlightening analytical results.

We use this game to highlight how debt renegotiation affects default incentives ex-ante and, crucially, how the level of the risk-free interest rate—which determines the lenders' outside option—affects the negotiated terms.

Details of the environment: Time is discrete and runs forever. There is a small-open economy populated by a government with preferences for streams of consumption represented by

$$\mathbb{E}_t\left[\sum_{s=t}^{\infty}\beta^{s-t}u\left(c_s\right)\right], \tag{3}$$

where $\beta \in (0,1)$ is a discount factor and u is continuously differentiable, strictly increasing, and strictly concave. Each period, the government receives a stochastic endowment $y_t \in (0,2)$, which is iid over time with $\mathbb{E}\left[y_t\right] = 1$ and CDF $F\left(y\right)$.

The government can issue one-period bonds b_{t+1} that pay one unit of the good in $t+1$ in case of no default. Debt is purchased by a measure one of identical risk-neutral lenders with deep pockets who also have access to a risk-free bond that pays a fixed interest rate r. In the full model, in the next section, r varies stochastically to reproduce the Volcker shock. In this section, we treat r as a parameter, and we show our results by performing simple comparative statics for different values of r. Therefore, we express all equilibrium objects as functions of this parameter r.

At the beginning of each period, and given some stock of debt b_t, the government observes the realization of y_t and decides whether to repay its outstanding debt. If the debt is paid, the government chooses consumption and issuance of new debt.

Following default, the government is excluded from financial markets, and income is $\lambda < 1$. Opportunities arise to negotiate the debt with probability θ every period. Once an opportunity to negotiate arises, the government and the lenders play an instantaneous—without discounting—game of alternating offers, in which there is a constant probability of the game terminating without agreement, so that the status quo prevails, as in Binmore, Rubinstein and Wolinsky (1986).

The object of the bargaining game is ρ, which represents the coupon the government will pay forever. We then consider the limit of that game as the time interval between offers goes to zero. As shown in Binmore, Rubinstein and Wolinsky (1986), the unique sub-game perfect equilibrium of such a renegotiation game implies an immediate agreement with an outcome equivalent to the Nash bargaining solution in which the outside options are given by the status quo.

After renegotiation, the government receives a constant stream of income equal to 1 forever, out of which it consumes $1 - \rho > 0$ in each period. The value $\rho > 0$ is captured by the lenders (that is, it cannot be defaulted on) and, as argued above, is the solution of the Nash bargaining problem.

In the model, agreements in equilibrium are reached at the first possibility of renegotiation, because $\lambda < 1$ implies that there is a strictly positive surplus that can be split. As we will show, however, it is the possibility of rejecting and waiting that allows the interest rate to have an important role in the determination of the equilibrium value of the outcome of the renegotiation game ρ^*.

Equilibrium: To define and characterize the equilibrium, we proceed backwards by characterizing the outcome of the renegotiation game ρ^*. We guess and then verify that it is unique. We then use this characterization to define the equilibrium of the model.

Renegotiation: Given some renegotiation outcome ρ, the value of the government in autarky after renegotiation is $V^A(\rho) = \frac{u(1-\rho)}{1-\beta}$. Thus, the value of the government in default is:

$$V^D(\rho) = \frac{u(\lambda)}{1-\beta(1-\theta)} + \frac{\beta\theta V^A(\rho)}{1-\beta(1-\theta)}. \tag{4}$$

Similarly, the value of a representative lender who holds defaulted bonds when the renegotiation outcome is ρ is:

$$Q^D(\rho) = \frac{\theta}{1+r} Q^A(\rho) + \frac{1-\theta}{1+r} Q^D(\rho), \tag{5}$$

where $Q^A(\rho) = \frac{1+r}{r}\rho$ is the value for the lenders of receiving ρ every period once the renegotiation game is settled. Guessing that the equilibrium outcome will be the same value ρ—regardless of the timing of its resolution—we plug Q^A into equation (5) and get that the value of holding defaulted bonds is

$$Q^D(\rho) = \frac{\theta}{r}\frac{1+r}{\theta+r}\rho, \tag{6}$$

which is strictly decreasing in r. When an opportunity to renegotiate arises, lenders and the government engage in Nash bargaining. We define the outcome $\rho^*(r)$ as

$$\rho^*(r) = \arg\max_{\tilde{\rho}} \left[S^{LEN}(\tilde{\rho})\right]^{\alpha} \left[S^{GOV}(\tilde{\rho})\right]^{1-\alpha} \tag{7}$$
$$s.t. \quad S^{GOV}(\tilde{\rho}) = V^A(\tilde{\rho}) - V^D(\rho^*(r)) \geq 0,$$
$$S^{LEN}(\tilde{\rho}) = Q^A(\tilde{\rho}) - Q^D(\rho^*(r)) \geq 0,$$

where $\alpha \in [0,1]$ is the lenders' bargaining power and S^{GOV} and S^{LEN} are the surpluses of the government and the lenders, respectively. Note that both participation constraints consider the outside option to be the value of remaining in default and waiting for a future renegotiation with outcome $\rho^*(r)$.[1]

[1]These values represent the outcome in the event that the bargaining process does break down, which are the status-quo values that must be used for the Nash bargaining solution to be the outcome of the unique sub-game perfect equilibrium of the bargaining game, as shown in Binmore, Rubinstein and Wolinsky (1986).

If we assume an interior solution, the first-order condition of the problem in (7) is

$$\alpha\left[\frac{u(1-\rho^*(r))-u(\lambda)}{1-\beta(1-\theta)}\right]-\frac{(1-\alpha)r}{\theta+r}\frac{u'(1-\rho^*(r))}{1-\beta}\rho^*(r)=0, \tag{8}$$

where we have used the definitions of V^A, V^D, Q^A, and Q^D above.

Proposition 1. There is a unique $\rho^* \in [0,1]$ that solves the bargaining problem in (7), which is decreasing in r.

Proof: The left-hand-side of equation (8) is positive for $\rho^* = 0$ (since u is increasing and concave) and becomes negative as $\rho^* \to 1$. By the intermediate value theorem, there is a $\rho^* \in [0,1]$ that satisfies equation (8). In addition, since u and u' are monotonic, this solution ρ^* is unique.

If $\alpha = 1$, then $\rho^*(r) = 1-\lambda$, and if $\alpha = 0$, then $\rho^*(r) = 0$, regardless of the value of r. For any $\alpha \in (0,1)$ we can rearrange equation (8) to get

$$\frac{u(1-\rho^*(r))-u(\lambda)}{u'(1-\rho^*(r))\rho^*(r)}=\frac{1-\alpha}{\alpha}\frac{1-\beta(1-\theta)}{1-\beta}\frac{r}{\theta+r}, \tag{9}$$

where the left-hand-side is decreasing in $\rho^*(r)$ (this follows from u being increasing and concave) and the right-hand side is strictly increasing in r. If the interest rate increases, then the right-hand side increases, so $\rho^*(r)$ must decrease for the left-hand side to increase for the equality to hold. This implies that the unique renegotiation outcome ρ^* is decreasing in the parameter r.□

For r to have an impact on the renegotiation outcome, it is crucial that both parties have something to gain from the renegotiation game. The fact that both parties have the possibility of choosing to delay the renegotiation process guarantees that both get a positive value out of the game as long as both have some bargaining power.

Recursive formulation: Given the above characterization of the renegotiation game, the value of the government in good financial standing is

$$V(b,y;r)=\max_{d\in\{0,1\}}\left\{dV^D(\rho^*(r))+(1-d)V^P(b,y;r)\right\}, \tag{10}$$

where d is the default decision. The value of repaying the debt is

$$V^P(b,y;r) = \max_{c,b'} \{u(c) + \beta \mathbb{E}[V(b',y';r)]\} \tag{11}$$
$$s.t. \quad c + b \leq y + q(b';r)\,b',$$

where q is the price schedule for government bonds. Note that V^P is strictly increasing in y for any given b, so the default set $\mathcal{D}(b;r) = \left\{y \in (0,2)\,|V^P(b,y;r) < V^D(\rho^*(r);r)\right\}$ is characterized by a cutoff value $y^*(b;r)$ such that

$$V^P(b, y^*(b;r);r) = V^D(\rho^*(r)). \tag{12}$$

Equilibrium: An equilibrium is value functions V, V^P, and V^D, policy functions d and b', a price schedule q, and a renegotiation outcome ρ^* such that (i) ρ^* solves the bargaining problem in (7); (ii) given ρ^* and q, the value and policy functions solve the functional equations (10) and (11); and (iii) given ρ^* and d, the price schedule is actuarially fair:

$$q(b';r) = \frac{1 - F(y^*(b';r))}{1+r} + \frac{F(y^*(b';r))}{1+r}\frac{Q^D(\rho^*(r))}{b'}, \tag{13}$$

where y^* is the cutoff value implied by the policy function d.

3.1 Renegotiation matters

The risk-free rate r affects default incentives ex-ante through two mechanisms.

The first, which we call the *standard mechanism*, refers to how r affects the budget constraint of the government in repayment through its direct effect on how lenders discount the future (the denominators in the pricing equation (13)). This direct effect reduces $q(b';r)$ in (6), tightening the government's budget constraint.

The second, which we call the *renegotiation mechanism*, refers to how r affects the renegotiation outcome ρ^* and, through it, how it shifts the price schedule q and the value of defaulting V^D. Equation (6) shows that a larger interest rate reduces the lenders' outside option in the bargaining game because their opportunity cost of delaying collection of payments increases. This makes them willing to accept a lower value for ρ^* and, in turn, reduces the ex-ante value of its debt q through the second term in the pricing equation (13). Thus, this better outcome both increases the value of default through a higher value after renegotiation and reduces the value of repayment through a tighter budget constraint.

Proposition 2. Let r, r' be such that $0 < r \leq r'$. For any b such that the repayment sets are not empty for r and r', the default set is expanding in r. That is, $\mathcal{D}(b; r) \subseteq \mathcal{D}(b; r')$.

Proof: Proposition 1 implies that V^D is increasing in r. Also, it is clear from equation (11) that V^P is decreasing in r. Then, for equation (12) to hold, y^* must also increase as r increases.□

Proposition 2 provides the main result of this section: default incentives are increasing in r. The intuition is that high interest rates improve the government's value of defaulting because they improve the terms that it would get out of an eventual renegotiation. In the absence of endogenous renegotiation, the interest rate would still affect default incentives, but only through the standard mechanism.

Suppose there is a counterfactual economy in which debt recovery is fixed: $\rho^* = \kappa \in (0, 1)$. The value of repayment in equilibrium becomes

$$V^P(b, y; r, \kappa) = \max_{b'} \{u(c) + \beta \mathbb{E}[V(b', y'; r, \kappa)]\} \tag{14}$$

$$s.t. \quad c + b \leq y + \frac{1 - F(y^*(b'; r, \kappa))}{1 + r} b' + \frac{\theta F(y^*(b'; r, \kappa))}{(\theta + r) r} \kappa,$$

and the cutoff y^* is now defined by

$$V^P(b, y^*(b; r, \kappa); r, \kappa) = V^D(\kappa). \tag{15}$$

The risk-free rate is irrelevant for the payoffs after default in this case. The limit $\kappa \to 0$ corresponds to a model in which lenders recover nothing after default and the government remains in autarky forever. This limiting case would further undermine the role of the standard mechanism by eliminating the second term in the budget constraint from equation (14).

In a sense, our previous assumptions make the above model almost static. In the next section we study a dynamic sovereign default model to include the renegotiation mechanism that we highlight in this section.

4 Quantitative model

We now extend our simple model into a quantitative sovereign default model with renegotiation. The key additions are shocks to the real interest rate and readmission to financial markets after debt renegotiation. We also allow for long-term debt and persistent income shocks. Given these assumptions, we cannot prove results similar to Propositions 1 and 2, but as will be clear, the intuition behind both results persists in our numerical analysis of the model.

Shocks and preferences: The risk-free interest rate can take two values $r_t \in \{r_L, r_H\}$, with $r_L < r_H$, and follows a Markov chain where π_{ij}, with $j \in \{L, H\}$, are the transition probabilities. Each period, the economy receives a stochastic endowment of a tradable good y_t that follows a log-normal AR(1) process $\log(y_t) = \rho \log(y_{t-1}) + \epsilon_t$, with $|\rho| < 1$ and $\epsilon_t \sim N\left(0, \sigma_\epsilon^2\right)$. This model differs from the simple model in that the endowment follows this stochastic process regardless of the government's financial standing. The government has preferences for consumption in each period, represented by $u(c) = \frac{c^{1-\sigma}}{1-\sigma}$, and discounts the future at a rate β.

Debt and default: The government issues long-term, non-contingent debt in international financial markets. Our specification is similar to that of Hatchondo and Martinez (2009) in that a bond consists of a perpetuity with geometrically declining payments: a bond issued in period t promises to pay $\gamma(1-\gamma)^{j-1}$ units of the tradable good in period $t+j$, $\forall j \geq 1$. The law of motion for bonds is given by $b_{t+1} = (1-\gamma) b_t + x_t$, where b_t is the number of bonds due at the beginning of period t, γ is the fraction of bonds that mature each period, and x_t is the issuance of new bonds. Debt is purchased by a measure 1 of identical risk-neutral competitive lenders with deep pockets who discount the future at the current risk-free rate $1/(1+r_t)$. Given a value for b_t, and after the realization of the shocks, the government decides whether to repay or default. If it chooses to default, then it gets immediately excluded from financial markets. We follow Chatterjee and Eyigungor (2012) and assume the following asymmetric cost to output while the government is in default:

$$\phi(y_t) = \max\left\{0, \phi_0 y_t + \phi_1 y_t^2\right\}, \text{ where } \phi_0 < 0 < \phi_1. \tag{16}$$

At the beginning of each period after default, an opportunity to renegotiate the outstanding debt arises with probability θ.

Renegotiation: When an opportunity to renegotiate arises, lenders and the government engage in Nash bargaining to determine a new debt level b^R for the government to re-enter financial markets with. In the renegotiation period, after b^R has been determined, the government pays γb^R and is allowed to issue new debt. Readmission with b^R must be mutually beneficial, and we continue to assume that both the government and the lenders have the option to reject an offer and delay renegotiation for a later opportunity. As in the simple model, a delay does not happen in equilibrium, because the deadweight cost to output in default (in both the present and future periods) implies that there is always a positive surplus to split. Unlike the one in the simple model, however, the surplus is not constant, but rather dependent on both the current level of output—which determines real resources to be split—and on the level of the risk-free interest rate—which affects the lenders' outside option and the value of new debt that the government could issue. As was the case before, the renegotiated debt level b^R is a function only of the present and future surplus to be split and does not depend on how much debt was defaulted on. This is an important difference between our model and the one in Hatchondo, Martinez and Sosa Padilla (2014). In their environment, the exchanged debt depends on outstanding debt because the outside option of the lenders is the current market value of it. This is because they model voluntary debt exchanges that happen *instead of default*, rather than *after* default. They assume that if lenders reject the exchange, they can collect the current market value of the debt, while we assume that if they reject, then renegotiation is delayed to a future period.

Our bargaining game endogenously determines a haircut. Consequently, we do not impose an exogenous haircut, as is customary in the literature. This raises the question of what the appropriate benchmark is to which we should compare our model. We consider the two obvious alternatives. First, we compare our results with those from a model in which the haircut is 100 percent. Second, we consider a model with a fixed haircut calibrated to the observed haircut for Mexico, as is standard.[2] An attractive feature of this case is that we calibrate the bargaining power of the country in the model with the renegotiation mechanism to also match the same average haircut. Thus, by comparing these two cases, we can disentangle the effect of the haircut being endogenous.

[2] We thank Francisco Roch for suggesting this alternative benchmark.

4.1 Recursive formulation

The state of the economy is (b, y, r). The value function of the government in good standing is

$$V(b,y,r) = \max_{d\in\{0,1\}} \left\{(1-d)V^P(b,y,r) + dV^D(y,r)\right\}, \tag{17}$$

where d is the default decision. If the government decides to repay, it makes coupon payments γb and gets to issue new bonds. The value of the government in repayment is

$$\begin{aligned} V^P(b,y,r) &= \max_{c,b'} \{u(c) + \beta\mathbb{E}[V(b',y',r')]\} \\ s.t. \quad c + \gamma b &\leq y + q^P(b',y,r)[b' - (1-\gamma)b], \end{aligned} \tag{18}$$

where q^P is the price schedule of newly issued bonds. The value of the government if it chooses to default is

$$V^D(y,r) = u(h(y)) + \beta\left\{\theta\mathbb{E}\left[V^P\left(b^R(y',r'),y',r'\right)\right] + (1-\theta)\mathbb{E}\left[V^D(y',r')\right]\right\}, \tag{19}$$

where $h(y) = y - \phi(y)$ is the output net of default costs and $b^R(y',r')$ is the value of renegotiated debt when the state is (y',r'). When an opportunity to renegotiate arises, b^R is determined as

$$\begin{aligned} b^R(y,r) &= \arg\max_{\tilde{b}} \left\{\left[S^{LEN}(y,r)\right]^{\alpha}\left[S^{GOV}(y,r)\right]^{1-\alpha}\right\} \\ s.t. \quad S^{LEN}(y,r) &= \left[\gamma + (1-\gamma)q^P\left(b^P\left(\tilde{b},y,r\right),y,r\right)\right]\tilde{b} - Q^D(y,r) \geq 0, \\ S^{GOV}(y,r) &= V^P\left(\tilde{b},y,r\right) - V^D(y,r) \geq 0, \end{aligned} \tag{20}$$

where b^P is the policy function of the government's problem in repayment (18) and $Q^D(y,r)$ is the value of a representative lender holding defaulted bonds:

$$\begin{aligned} Q^D(y,r) = &\frac{\theta}{1+r}\mathbb{E}\left[\left\{\gamma + (1-\gamma)q^P(b'',y',r')\right\}b^R(y',r')\right] \\ &+ \frac{1-\theta}{1+r}\mathbb{E}\left[Q^D(y',r')\right], \end{aligned} \tag{21}$$

with $b'' = b^P\left(b^R(y',r'), y', r'\right)$. The participation constraints in (20) capture how both the government and the lenders have the option to delay renegotiation for a future opportunity.

The relation between the renegotiated debt b^R and the risk-free rate r is not as transparent as in the simple model, but the same intuition laid out in the latter persists. Equation (21) shows that when the risk-free rate is high, lenders discount the future at a higher rate, which directly lowers their outside option Q^D. Thus, with high r, lenders are more willing to accept a lower b^R since they value immediate payments more than potentially higher future ones. The government understands that it will get better terms if renegotiation happens when the risk-free rate is high. So, if interest rates are expected to remain high, then high interest rates in the present make default more attractive through expectations of better renegotiation terms (low b^R if renegotiation happens while r remains high).

The price of debt in good financial standing q^P reflects the actuarially fair value of newly issued bonds b':

$$\begin{aligned} q^P(b',y,r) = & \frac{1}{1+r}\mathbb{E}\left[\left\{1 - d(b',y',r')\right\}\left\{\gamma + (1-\gamma)\, q^P(b'',y',r')\right\}\right] \\ & + \frac{1}{1+r}\mathbb{E}\left[d(b',y',r')\,\frac{Q^D(y',r')}{b'}\right], \end{aligned} \tag{22}$$

where $b'' = b^P(b',y',r')$ is the government's debt issuance if it repays in the next period.

Equation (22) shows how the risk-free rate affects the price of debt through both mechanisms. Through the *standard mechanism*, an increase in r lowers the market value of debt because it increases the rate at which lenders discount the future. This decreases how much the government can raise from a new debt issuance, which in turn makes default more attractive. Through the renegotiation mechanism, Q^D decreases when the interest rate is high if it is expected to remain high when an opportunity to renegotiate arrives. This further decreases q^P by making the second term in equation (22) lower. If the recovery value were exogenously fixed, this last effect would vanish. A higher r would still make default more attractive but only through its direct effect on the government's budget constraint due to q^P shifting downward. Moreover, this shift would be driven only by the standard mechanism, since Q^D in the right-hand side of equation (22) would be invariant to r.

Equilibrium: An equilibrium is value and policy functions for the government, a price schedule q^P, a value of holding defaulted debt Q^D, and a function for renegotiated bonds b^R such that: (i) given q^P, Q^D, and b^R, the value and policy functions of the government satisfy equations (17), (18), and (19); (ii) given b^R and the government's policy functions, the value Q^D satisfies the functional equation (21); (iii) given the value and policy functions of the government, and given Q^D, b^R solves the bargaining problem in (20); and (iv) given the policy functions and Q^D, the price q^P satisfies equation (22).

4.2 Calibration

We consider the 1982 debt crisis of Mexico, which was the first country to default. We use our model to assess whether renegotiation dynamics play an important role.

Table 2 presents all parameter values that we calibrate directly. Each period in the model corresponds to 1 year. The risk aversion parameter is set to a standard value, $\sigma = 2$. As mentioned, the probability of renegotiation is set to roughly once every five years on average, or $\theta = 0.19$, as implied by Gelos, Sahay and Sandleris (2011). The AR(1) income process estimation uses HP-filtered logged Mexican GDP data from 1921 to 1983, which yield an auto-correlation parameter $\rho = 0.705$ and a standard deviation of innovations of $\sigma_\epsilon = 0.040$. We set $\gamma = 0.75$ so that the average bond duration equals 16 months, which was the average maturity of the outstanding syndicated loans Mexico had by 1982 (see Negrete Cardenas (1999)).

Table 2: Externally calibrated parameters

Parameter		Value	Details
low r	r_L	0.012	1955 - 1980
high r	r_H	0.062	1981 - 1985
Pr(low to high r)	$\pi_{L,H}$	0.01	Duration of 100 years
Pr(high to low r)	$\pi_{H,L}$	0.20	Duration of 5 years
Pr(renegotiation)	θ	0.19	5.2 years exclusion (Gelos, Sahay and Sandleris (2011))
maturity rate	γ	0.75	Sixteen-month bonds
risk aversion	σ	2	Standard
income process	ρ	0.705	AR(1) estimation
	σ_ϵ	0.040	annual data 1933-1983

The probability of switching from the high risk-free interest rate regime to the low one is set to $\pi_{H,L} = 0.20$ so that it generates an expected duration of 5 years for the high regime. This is the time it took interest rates in the U.S. to start decreasing, as can be seen in Figure 4. We set the probability of switching from the low to the high risk-free interest rate regime to $\pi_{L,H} = 0.01$ so that shocks like the one we are studying are very infrequent events.

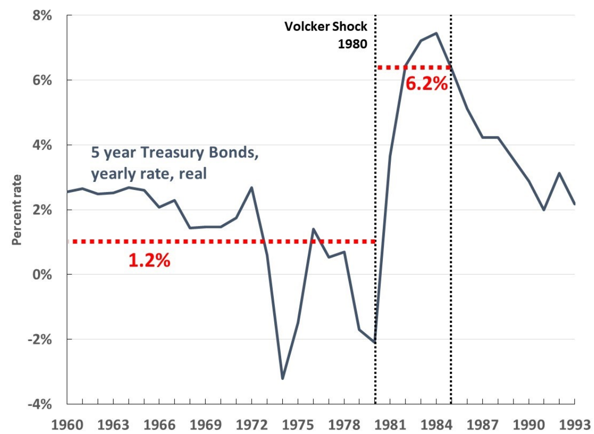


Figure 4: Real risk-free interest rate

Source: The data for the U.S. real interest rate were retrieved from FRED, Federal Reserve Bank of St. Louis.

Figure 4 also displays the average interest rate during the Volcker shock (1980–1985) and the average interest rate before that (1955–1980). Therefore, we set the risk-free interest rate in the low regime to $r_L = 0.012$, and to $r_H = 0.062$ in the high regime.

We set the lenders' bargaining power parameter α, the discount factor β, and the output cost parameters ϕ_0 and ϕ_1 to jointly match four moments of the Mexican economy: a haircut of 0.24 following the Brady Plan, an average debt-to-GDP ratio of 0.19, a default probability of 0.03, and an average spread of 0.03. Column (1) in Table 3 reports the parameter values for the benchmark calibration.

Table 3: Parameters chosen to match data moments

		Benchmark parameters (1)	Full exogenous haircut (2)	Partial exogenous haircut (3)	Targets from data	
Bargaining power	α	0.11	n.a.	n.a.	Haircut in 1990	0.24
Discount factor	β	0.82	0.77	0.89	Debt-to-GDP ratio	0.19
Income	ϕ_0	-0.20	-0.62	-0.46	Default probability	0.03
cost function	ϕ_1	0.23	0.69	0.49	Average spreads	0.03

To quantify the relevance of the renegotiation mechanism, we consider two alternative economies in which the haircut to defaulted debt is determined exogenously. That is, we assume that, once a renegotiation opportunity arrives, the government is readmitted to financial markets with a debt level equal to $b^R = (1-\kappa)b$, where $\kappa \in [0,1]$ is the exogenous haircut. We also assume that the government can choose to reject this offer, in which case defaulted debt remains at b and the government continues to be in autarky until a new opportunity arrives. The value in default is now a function of the level of debt that the government defaulted on, b:

$$V_{\kappa}^{D}(b,y,r) = u(h(y)) + \beta\left\{\theta\mathbb{E}\left[V_{\kappa}((1-\kappa)b,y',r')\right] + (1-\theta)\mathbb{E}\left[V_{\kappa}^{D}(b,y',r')\right]\right\}, \tag{23}$$

where the continuation value

$$V_{\kappa}(b,y,r) = \max_{d\in\{0,1\}}\left\{(1-d)V_{\kappa}^{P}(b,y,r) + dV_{\kappa}^{D}(b,y,r)\right\} \tag{24}$$

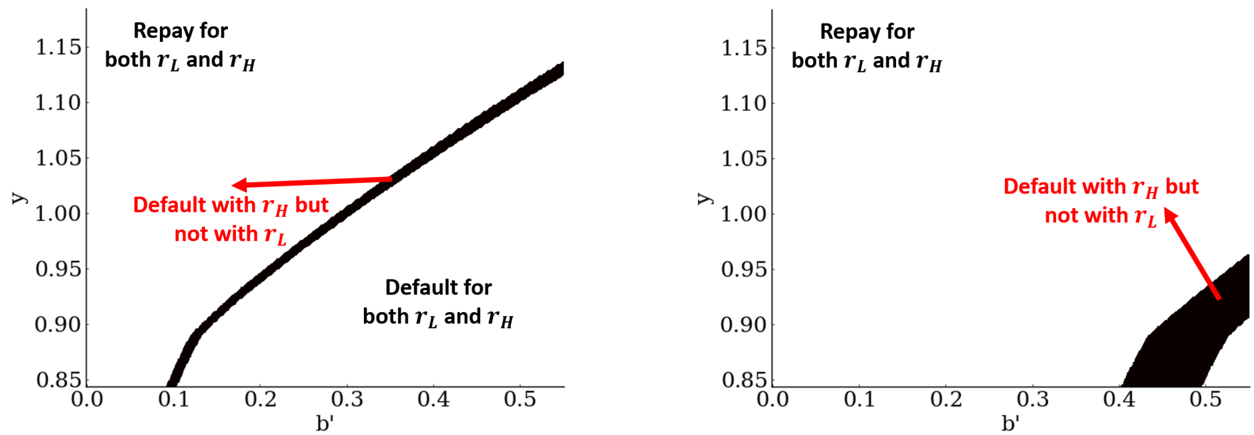
considers the government's ability to choose to remain in default, and V_{κ}^{P} and all other objects are defined as before. We consider two cases: the case of full exogenous haircut with $\kappa = 1$, and the case of partial exogenous haircut with $\kappa = 0.24$, the relevant value for Mexico.[3] For each of these cases, we recalibrate the model to match the same moments as in the benchmark. Columns (2) and (3) of Table 3 report the corresponding parameter values.

4.3 Interest rate shocks and default

To analyze how renegotiation affects default incentives and, more importantly, the ability of interest rate hikes to induce defaults, we divide the state space into three regions for pairs of income and debt (y,b): (i) one in which the government defaults for any risk-free interest rate, (ii) one in which it repays for any risk-free interest rate, and (iii) the region in which the government defaults only when the risk-free interest rate is high.

The left panel of Figure 5 presents these regions for the case in which there is no renegotiation and no debt recovery. This corresponds to the calibration in Column (2) of Table 3, which is the case where $\kappa = 1$ (or $\alpha = 0$, as discussed in footnote 3). The right panel presents these regions for the same calibration but setting $\alpha = 0.20$.

[3] Note that the case of $\kappa = 1$ is nested by the benchmark model by setting $\alpha = 0$. This gives the government all the bargaining power and allows it to make take-it-or-leave-it offers to the lenders. The lenders are still allowed to delay and wait for a future opportunity to receive a similar deal. In equilibrium, the value of any future renegotiation is erased by the government having all the bargaining power at all times, which pushes the lender's outside option to 0.



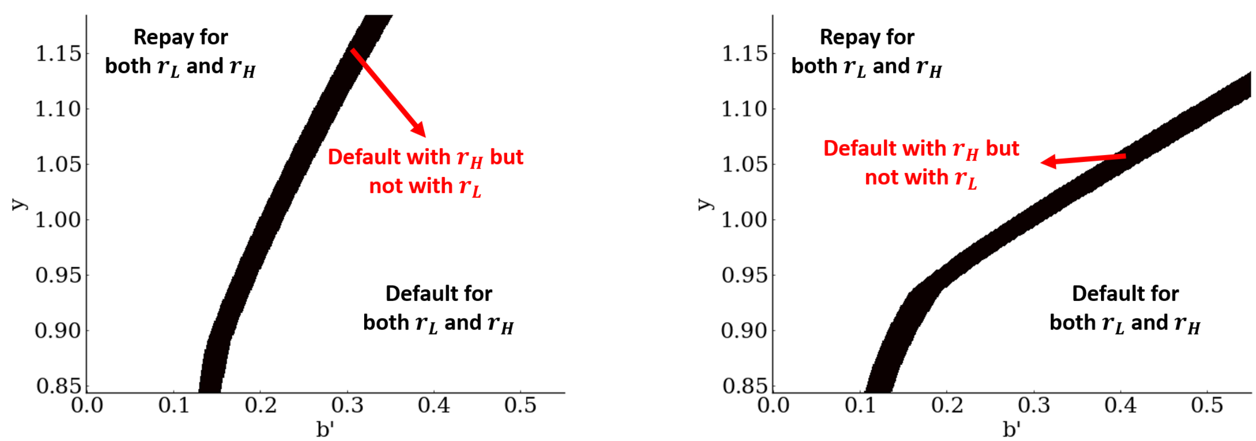
(a) No renegotiation, no recovery

(b) Renegotiation with $\alpha = 0.2$

Figure 5: Default regions, effect of renegotiation

Introducing renegotiation has two important implications in the model. First, it allows the government to sustain higher levels of debt. This is because lenders expect some positive recovery after a potential default, so for any given default probability implied by some state, the market value of debt is higher. Second, it expands the region in which default happens only with high interest rates (the black region).

Figure 6 presents the same regions for the benchmark model with renegotiation and the counterfactual case with an exogenous fixed haircut of $\kappa = 0.24$.



(a) Renegotiation, benchmark

(b) Fixed exogenous haircut, $\kappa = 0.24$

Figure 6: Default regions

Note that the black regions are thicker than their counterpart in the left panel of Figure 5. This highlights the role of renegotiation—as the comparison of both cases in Figure 5 did—but it also stresses the role of debt recovery after default, even if it is exogenous. Note that the black region is more vertical, however, in the case of endogenous renegotiation. This implies that for a given level of debt, there is a larger range of income shocks that would be consistent with a default triggered solely by an interest rate hike.

The above analysis of default sets is akin to comparing policy functions of different models, which allows to understand how endogenous decisions drive simulated outcomes. We now analyze default events in the ergodic distribution of each case. For each model, we simulate 1,000,500 periods and drop the first 500 to avoid results being driven by initial conditions. We use these time series to compute the probability of an interest-rate hike triggering a default event; that is,

$$\xi = \Pr\left(d_t = 1 | d_{t-1} = 0, r_t = r_H, r_{t-1} = r_L\right). \tag{25}$$

Table 4 reports this statistic for all three cases.

Table 4: Probability of interest rate hikes triggering a default

	No renegotiation, no recovery	Fixed exogenous haircut	Endogenous renegotiation
$\xi = \Pr$ (default event|interest-rate hike)	0.05	0.12	0.21

In the model with no renegotiation and no debt recovery, only 5 percent of interest rate hikes trigger a default. This makes the usual narrative that the Volcker shock was an important driver of the Latin American defaults unlikely. In contrast, in our benchmark model, this number is 21 percent. Just the expectation of some debt recovery, even if it is independent of the interest rate, more than doubles the likelihood of interest rate shocks triggering a default (from 0.05 to 0.12). This is almost doubled again from 0.12 to 0.21 if this recovery endogenously depends on the level of the interest rate, which is our *renegotiation mechanism*. [4]

The numbers just discussed were computed for all possible realizations of output. But as Figures 5 and 6 make clear, given the calibrated value of the debt, the decision to default depends on both the interest rate and the output shocks. In Table 5 we report several results that help

[4] A referee suggested an alternative mechanism: If a large fraction of the debt is dollar denominated and a Volcker shock generates a depreciation of the local currency, the debt to output level can increase. This additional revaluation effect can amplify the role of the Volcker shock. We considered this possibility in the Appendix. As expected, the probability of default following a Volcker shock increases in all cases. Still, our renegotiation mechanism substantially amplifies the effect.

quantify this interaction in the context of the calibrated model.

Table 5: Probability of default

	No renegotiation, no recovery	Fixed exogenous haircut	Endogenous renegotiation
only Volcker shocks	0.05	0.12	0.21
only Volcker shocks with high y	0.00	0.00	0.01
only Volcker shocks with low y	0.10	0.25	0.43
no Volcker shock with low y	0.06	0.08	0.05

As was the case before, each column corresponds to a particular model. The first row shows the probability of default following an interest rate shock for the benchmark case presented in Table 4. The second row presents the same probabilities but conditional on output being above the unconditional mean—roughly half of the observations. These numbers highlight that only when output is below the mean can the interest rate shocks lead to a default.

The third row shows the probabilities for values of output below the unconditional long-run value—the other half of the observations. Not surprisingly, given the numbers in the previous two rows, probabilities are close to twice the ones on the first row. In particular, in the model with endogenous renegotiation, a Volcker shock leads to a default almost half the time, conditional on output being below its unconditional mean. Finally, the last row shows the probability of default conditional on low output and conditional on the absence of a Volcker shock. A comparison of the third and fourth rows allows us to evaluate the role of the Volcker shock. In the case of no recovery, the Volcker shock increases the probability of default when output is low by a factor of 1.6. In the model with partial but fixed haircut, the Volcker shock increases the probability of default by a factor of 3.1. Finally, in our model with endogenous renegotiation, the Volcker shock increases the probability of default by a factor of 8.6. In this sense, our model goes a long way in reconciling the standard narrative and the sovereign default literature. [5]

We now compare default episodes in the benchmark model with those in the model with no debt recovery. Figure 7 displays the average paths around default episodes of income shocks, the

[5] We repeated our exercise in models with higher costs of adjusting the debt, following a suggestion of one referee. As we show in the Appendix, the results are robust to such modifications.

risk-free interest rate, and a hypothetical haircut:

$$\text{haircut}_t = 1 - \frac{b^R(y_t, r_t)}{b_t}, \tag{26}$$

where b^R is the renegotiation outcome defined in (20). This is the haircut that would occur if a renegotiation had happened in period t with the shock realizations (y_t, r_t) and the defaulted debt had been b_t. We simulate 10,000 default episodes and compute the average paths in a 20-period window around each.

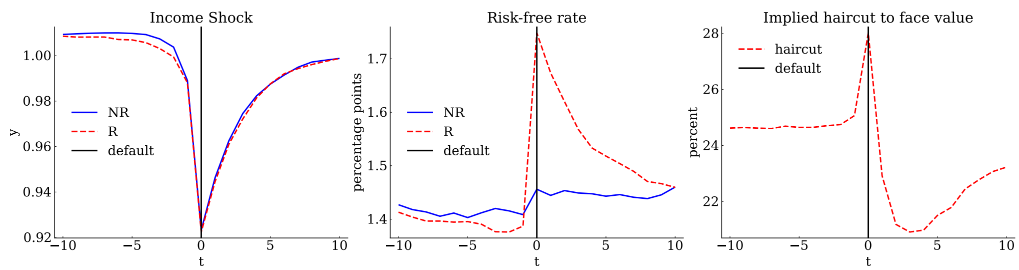


Figure 7: Paths around default events

While the pattern of income shocks is pretty similar in both models, interest rate hikes are substantially more associated with default in the model with endogenous renegotiation. Also, note that the hypothetical haircut substantially increases in the periods leading up to the default event; this result stresses the role that better expected terms for the government play in triggering the default decision. Given the persistence of the income and risk-free interest rates, the anticipation of more favorable restructuring terms makes defaulting more attractive and borrowing more expensive. This mechanism is nonexistent in the two counterfactual models with exogenous fixed debt relief.

Figure 8 shows the distributions of realized haircuts conditional on each interest rate level. The distribution under low interest rates has a lower variance, and haircuts are more concentrated around the targeted average. In contrast, the distribution under high interest rates is much more volatile and slightly skewed to the left. The higher mode and higher average of realized haircuts capture the government's improved bargaining conditions when interest rates are high.

The fatter left tail with high r captures another interesting feature of the model. Governments gamble on receiving generous haircuts: their realized haircut is high when the persistent risk-free interest rate remains high, but it is much lower if there is a switch back to a low r. These last ones

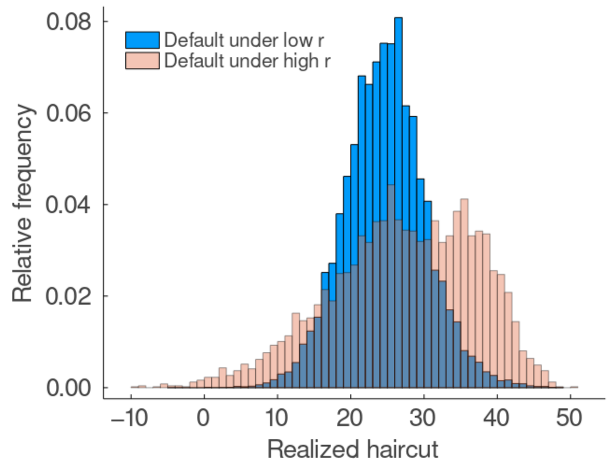


Figure 8: Distribution of haircuts

are the "unlucky" cases (for the government) in the left tail of the distribution under the "default in high r" regime.

This was the case for Mexico. It was only in 1989 that Mexico managed to renegotiate with the lenders and end the default episode in 1990. This was eight years after the default, and it was indeed during a year of low real interest rates.

Bad luck is indeed the interpretation offered by the model. The expected renegotiation occurs on average after five years, and Mexico had a bad draw. But this interpretation does not survive the test of history, as we discuss this in the next section, where we also argue that a more accurate interpretation raises doubts regarding the way we calibrated the parameter that governs the probability of renegotiation.

4.4 Causes and consequences of the delayed renegotiation

We now briefly review the events that unfolded following Mexico's default. We focus on the role played by U.S. government officers and regulators in the episode. In our view, this narrative raises doubts regarding the calibration of the parameter governing the probability of a renegotiation opportunity.

In a nutshell, the argument goes as follows: in defaulting, Mexico was expecting to be able to reach an agreement with its creditor relatively soon. In fact, within six months after the default, Mexican leaders initiated attempts to renegotiate with the banks. After Mexico defaulted, however, other countries followed. Because of a lack of prudent behavior on the side of banks, the losses generated by all these default episodes were, in some cases, almost as large as the capital of the banks.

The perception was that a failure of some of the banks could create a bank panic similar to the one during the Great Depression, and the situation raised serious concerns among U.S. regulators. The "too big to fail" doctrine took hold, and banks were not allowed to write off some of their losses until it was deemed safe to do so. At the same time, the banks saw an opportunity to be bailed out by the U.S. government, as the quotations below attest. The resolution of the default episodes of the 80s was the outcome of a game much more complicated than the standard sovereign debt model that we solved: it involved the sovereign, the lenders, and the U.S. regulators. Both the banks and the US regulators saw benefits in delaying the renegotiation, a factor that was not necessarily in the cards when Mexico decided to default in the summer of 1982.

In our benchmark calibration, following standard practice, we assumed the probability of having a renegotiation opportunity to be about 1 every 5 years. Relative to the specific experience of Mexico, this number appears to be too optimistic. In what follows, we argue exactly the opposite: a natural assumption for Mexico in August of 1982 was that the perceived probability of a renegotiation was substantially higher than 1 every 5 years—the value we used in the calibration.

To make our case, which is heavily influenced by Dooley (1995), Seidman (2000), and Silber (2012), we briefly review, in the next sub-section, the major events in international financial markets since the 70s.

4.4.1 The role of U.S. banks and U.S. regulators in the 1980s debt crisis

During the Bretton Woods period, international financial markets were dominated by official lending to developing countries. The change came about after the massive wealth redistribution across countries that followed the oil shock of the early 70s. The oil-rich countries amassed huge savings, and governments of developed economies were reluctant to intermediate and redirect these funds to emerging economies.

There is little doubt that the exposure of several major U.S. banks to Latin American debt was beyond prudent bank management. And to some extent, regulatory failures explain that behavior. For example, loans to a single borrower could not exceed 10 percent of bank's capital; nevertheless, regulators allowed different government agencies in foreign countries to be considered as different borrowers. As a consequence, exposure to a single country's sovereign institutions far exceeded 10 percent in many cases. There is even indication that banks were encouraged by official sources to engage in lending to Latin American countries. For example, Lewis William Seidman, former head of the U.S. Federal Deposit Insurance Corporation, claims in Seidman (2000) that there were non-profit-maximizing incentives for lending during the 1980s: "The entire Ford administration, including me, told the large banks that the process of recycling petrodollars to the less developed countries was beneficial, and perhaps a patriotic duty" (pg. 38).

As a consequence, it was only natural that banks reacted to the crisis by immediately trying to involve the banking authorities in their country in the process. As we will argue, they had every incentive to involve their own governments.

Other countries followed Mexico and defaulted on their debts, and all those debts combined amounted to a sizable fraction of the total capital of the banks. Therefore, it was also in U.S. regulators' interest to delay an agreement between the countries and the banks, since the total accumulated loss for the banks could have triggered a banking crisis in the United States.

Seidman (2000) argues that the renegotiation for Mexico took longer than expected and that the delay can partly be blamed on U.S. regulators, who did not allow banks to write down their defaulted debt: "U.S. bank regulators, given the choice between creating panic in the banking system or going easy on requiring our banks to set aside reserves for Latin American debt, had chosen the latter course. It would appear that the regulators made the right choice" (pg. 127).

Latin American defaults caused such problems for the U.S. banking system that concerns regarding the stability of the U.S. financial sector rivaled those about the tightening required to end inflation, the core objective of Volcker's first term in office, and the main reason why he is so well remembered as a Fed chair.[6]

Volcker's concerns with the emerging risks in financial markets were aired as early as May 1982, several months before the August crisis, which ended in Mexico's default. At the May 18th, 1982, FOMC meeting, Volcker said, "We face the possibility of surprises and uncertainties...I'd like to get the interest rates down, [and] it wouldn't hurt my feelings at the very least to give the

[6] The discussion that follows heavily borrows from Silber (2012), which contains a very rich and fascinating discussion of the events we are concerned about.

market a little sense of a lid in that direction" (Transcript, FOMC Meeting, May 18th, 1982, pg. 41).

Volcker had been closely following developments in Mexico since the country's balance of payments crisis in February 1982. He even arranged for two central bank swap lines to provide liquidity to the Bank of Mexico, involving in August of the same year his network of central bankers in the United Kingdom, Switzerland, and Japan, among others. Volcker himself arranged a meeting between the finance minister of Mexico, Silva Herzog, and representatives of the main U.S. commercial banks. According to Silber (2012), Volcker even asked officials of the New York Fed to host the meetings. Mexico got relief from the banks during that meeting. At the FOMC meeting on August 24th, 1982, Volcker said, "We are in a very sensitive period...And not just economically, but in terms of the markets...and in fact concern—and I am afraid to some degree justified concern—about the stability of the banking system. I am sure this is the time to be delicate and sensitive...I don't think we can be overly mechanical" (Transcript, FOMC Meeting, August 24th, 1982, pg. 18).

This statement leaves no doubts regarding Volcker's concern for the stability of the banking system. Together with his comments in the May 1982 FOMC meeting mentioned above, it suggests that faced with concerns about the health of U.S. banks, he was willing to consider easing policy, which could have complicated things on the inflation front. At the same August meeting, Henry Wallich, then a member of the Board of Governors, raised the concern of stimulating too much at a time in which the battle against inflation had not been won yet.

Finally, at the October 5th FOMC meeting, Volcker eventually decided in favor of the financial stability objective. He addressed the committee by saying that "There is a substantive need for a relaxation of pressures in the private markets in the United States... Extraordinary things may have to be done. We haven't had a parallel to this situation historically except to the extent that 1929 is a parallel." (Transcript, FOMC Meeting, October 5th, 1982, pg. 19.)

According to Silber (2012), the reference to the Great Depression was important to get a favorable vote to explicitly target a lower interest rate as the objective of monetary policy. This marked the abandonment of a two-year strategy of targeting monetary aggregates and, at the same time, the explicit adoption of a softer monetary policy. It is worth noting that in spite Volcker's conviction, there was resistance in the committee: the decision was taken with a split vote of 9 against 3.

In summary, in this perceived trade-off between inflation and financial markets stability, Volcker leaned towards the latter. This was a bold move. By October 1982, inflation had indeed dropped dramatically, but the high inflation years were still very vivid in everybody's memory. And so were the years right after 1976, when, after a substantial drop in inflation and a quick loosening of monetary policy during 1976 and 1977, inflation jumped up again in 1980 to its highest value since the end of World War II.

The problems created in the U.S. banking system became so pronounced that Volcker himself was summoned for a formal hearing in Congress in February 1983. Volcker's involvement with the banking crisis preceded his role as chair of the Fed. From 1975 to 1979, he was the president of the New York Fed. As such, he shared responsibility in the supervision of U.S. banks, including many of those involved in substantial lending to Latin American countries. His responsibilities obviously increased as he became chair in 1979. During the hearings, he acknowledged that the banking system faced "an unprecedented threat...we haven't had to deal with during the postwar period" (International Debt: Hearings Before the Senate Subcommittee on International Finance and Monetary Policy of the Committee on Banking, Housing and Urban Affairs, 98th Congress, 1st Sess., February 14th, 1983, pg. 258).

Senator John Heinz, chairman of the subcommittee, started the hearings by saying that "the U.S. bank debt problems would not have gotten to their present dangerous stage had our bank regulators not been asleep at the switch" (Ibid, pg. 237).

Senator William Proxmire, a member of the subcommittee, added, "Even though danger signals were apparent to all but the willfully obtuse, U.S. banks increased their exposure in Mexico during the first half of 1982 by $3.8 billion" (Ibid, pg. 237).

Asked if the regulators were forceful enough, Volcker replied, "I suppose, in retrospect, probably not" (Ibid, pg. 237).

These events conditioned the renegotiation game between Mexico and its creditors, starting a protracted period of negotiations that had no way to solve the problem, mostly because of the standoff between the banks and the U.S. regulators. On this point, Dooley (1995) (pg. 271) mentions that "the events following the debt crisis cannot be adequately modeled as a game involving only debtors (developing-country governments) and creditors (commercial banks). By leaving out the interested and relatively wealthy third parties (industrial country governments), this framework fails to capture the basic nature of the problems generated by the crisis."

This game between creditors evolved in clear favor of banks. According to Dooley (1995), in 1982, debtor countries owed about \$280 billion to the banks and another \$115 billion to official creditors. By the end of the decade, the real value of the debt to the banks was close to \$240 billion, but the real value of the debt to official lenders went up to about \$240 billion. The bank debt numbers are consistent with countries paying the full nominal value of the interest during these years, in which case the nominal value of the debt would have remained constant. With an accumulated inflation rate of roughly 20 percentage points, the real value of a \$280 billion debt would become about \$230 billion, very close to the number observed at the end of the 80s. How did the countries make all these interest payments? Probably partly with the positive trade balance observed during some of those years, but surely also by borrowing from institutional lenders, which explains the substantial increase in the real value of this type of debt.

Regarding the protracted period of renegotiation, Dooley (1995) concludes, "Neither the banks nor the creditor governments, however, saw any advantage to presenting their position with excessive clarity. Banks were winning the game as it was being played, and governments that had asserted they would not bail out the banks were not anxious to concede that they were doing slowly what they would not do quickly" (pg. 276).

4.4.2 Higher renegotiation probability

Modeling the much more complicated game between Mexico, the banks, and the U.S. government is beyond the scope of the paper. In the standard model of sovereign default, this change in the game can be quantified through the probability of renegotiation. The narrative of the debt crisis discussed above suggests that the relevant parameter for the probability of a renegotiation in Mexico in 1982, when the decision to default was made, was substantially lower than 1 every 5 years, the probability used in the benchmark calibration.

The ex-post value we use, following standard practice, is precisely the result of the very protracted process of renegotiation described in the previous section. This is consistent with the evidence in Gelos, Sahay and Sandleris (2011), which we use to calibrate the model, and in Reinhart and Rogoff (2009): both report an average default duration in the 90s that is roughly half of the duration they report for the 80s.

The chance of a quick renegotiation is essential in the theory, since the borrower gets better terms only if the bargaining game is played while the interest rate is still high. Thus, a key interaction for the renegotiation mechanism to play an important role is the persistence of the interest rate shock—the more persistent, the stronger the mechanism—and the likelihood of a fast renegotiation opportunity—the higher the likelihood, the stronger the mechanism. If we are correct, then the benchmark calibration underestimates the role of the renegotiation mechanism.

We therefore conclude this section by exploring the sensitivity of our results to changes in the parameter that governs the probability of having a bargaining opportunity. In Table 6, we report the results of the same calibrated model, but using an expectation that the chance to renegotiate arrives once every two years. We believe that this number is closer to what Mexico could expect in 1982.

Table 6: Probability of interest rate hikes triggering a default

	No renegotiation, no recovery	Fixed exogenous haircut	Endogenous renegotiation
$\Pr(\text{default}\vert\text{interest-rate hike}, \theta = 0.19)$	0.05	0.12	0.21
$\Pr(\text{default}\vert\text{interest-rate hike}, \theta = 0.50)$	0.07	0.25	0.41

In all cases, the probability of an interest rate hike triggering a default is larger, which makes the case for the Mexican default in 1982 even stronger. This is due to a lower penalty from a shorter exclusion from financial markets. Introducing renegotiation increases this probability because of the higher likelihood of favorable haircuts with high interest rates. The increase is even higher with a higher value of θ, which highlights the interaction between the persistence of high interest rates and the expected quick arrival of a renegotiation opportunity.

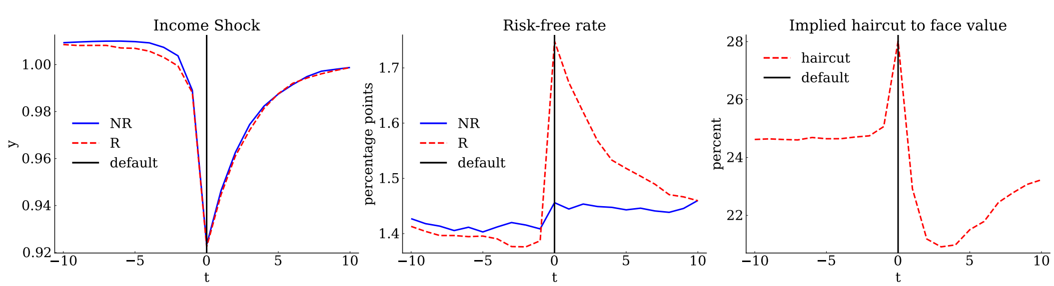


Figure 9: Paths around default events

Figure 9 is analogous to Figure 7 for this alternative exercise with higher θ. As was the case in the benchmark calibration, the implied haircut (the haircut that the government would get if it were to default in the given period) increases sharply in default episodes. This increase is driven by higher interest rates, which, given their persistence, are expected to remain high when a renegotiation occurs.

5 Numerical exploration

The previous section shows that the renegotiation mechanism is quantitatively important for a calibrated version of the model. In this section we explore the robustness of the results to alternative parameterizations of the model. To keep the exercise relatively simple, we fix the values of the parameters that we calibrated externally as shown in Table 2, with the single exception being the probability of renegotiation. In light of the discussion in Section IV.D, we allow it to take values between 0.2 and 0.5. We also define admissible intervals for the four parameters we calibrated using the four moments from Mexico for the model with endogenous renegotiation. We report these admissible intervals in Table 7.

Table 7: Parameter intervals for numerical exploration

parameter		min	max
probability of renegotiation	θ	0.20	0.50
discount factor	β	0.70	0.95
bargaining power	α	0.00	1.00
cost of	$knk = -\phi_0/\phi 1$	0.80	1.05
default	ϕ_1	0.05	1.05

We let the discount factor β be as low as 0.7 and as high as 0.95, which is high but still implies a relatively more impatient agent than the risk-free rate of 0.04, a standard value. We let the bargaining power of lenders α take any value between 0 and 1. For the parameters ϕ_0 and ϕ_1, we exploit the fact that the ratio $knk = -\phi_0/\phi_1$ defines a "kink" in the default cost formulated in equation (16) such that the cost is zero for realizations of $y \leq knk$, and positive and increasing for $y > knk$. We then choose a wide interval for knk and for ϕ_1 that contains values that have been previously used in the literature. For example, the default cost in Arellano (2008) is zero for shock realizations below $knk = 0.97\mathbb{E}[y]$. Chatterjee and Eyigungor (2012) set $\phi_0 = -0.18$ and $\phi_1 = 0.24$, which imply a relatively large cost of defaulting with $knk = 0.75$. Note, however, that the maturity of debt in our model is lower than in theirs, partly because of the calibration targets and partly because theirs is a quarterly model. We find that values of knk below 0.80 generate default probabilities that are very close to zero and very high average debt levels, which are uninteresting cases for our analysis. Note that the intervals contain the parameters we chose for Mexico in our calibrations in Table 3 for the cases of endogenous and exogenous haircuts.

For each of the five parameters in Table 7, we construct equidistant discrete sets of values and randomly chose a vector of five parameters using independent uniform distributions. For each vector of parameters, we simulate the model economy for 100,500 periods, discarding the first 500 observations. We then calculate the probability of an interest rate hike triggering a default for this numerical example, which is the same moment that we discussed in Tables 4 and 6 when considering the calibration for Mexico.

We repeat this exercise 50,400 times and compute the frequency distribution of the probability of an interest rate hike triggering a default, defined as ξ_i in equation (25), indexed here by the particular parametrization i. This frequency distribution is depicted in the top panel of Figure 10.

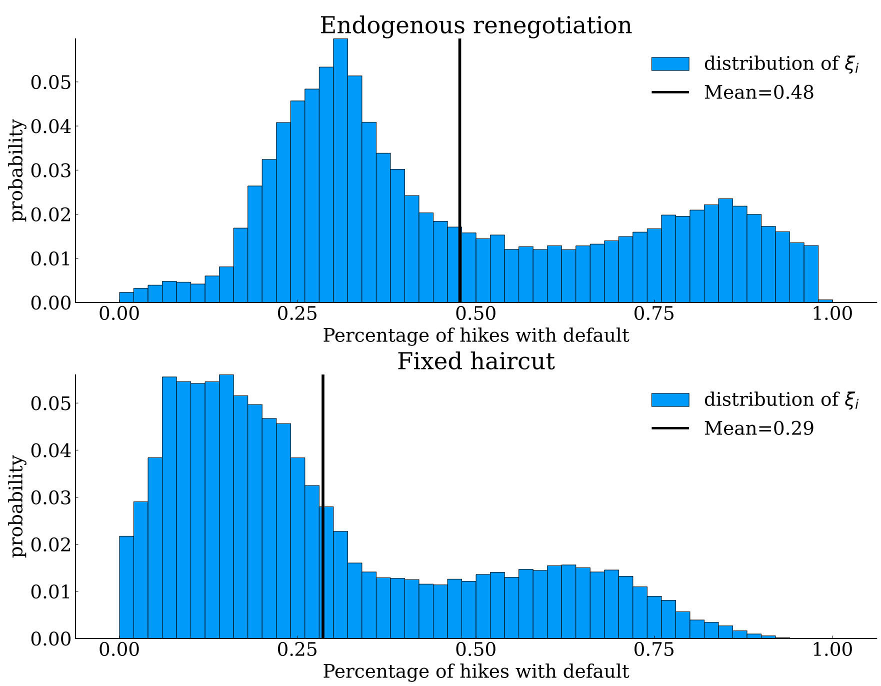


Figure 10: Distribution of the percentage of interest rate hikes triggering a default

Then, for each of the numerical economies solved above, we compute the average haircut and solve the model with an exogenous haircut equal to that average and with the same value for all the other parameters. Then, for each of these exogenous haircut models, we compute the probability of an interest rate hike triggering a default. The frequency distribution of those probabilities for the exogenous default model is presented in the bottom panel of Figure 10. The difference between the two distributions represents one measure of the renegotiation mechanism that we explore in this paper.

To compute the two distributions in Figure 10, we use the same values for parameters that are common in both models. As the models are different, they do not generate the same moments, in general, given the same parameters. Thus, Figure 10 shows unconditional distributions of the moment of interest. To further compare the performance of the two models on the probability of an interest rate hike triggering a default, we present in Table 8 a regression analysis of the simulated data used to construct Figure 10.

Table 8: Estimated effect of endogenous renegotiation on ξ

coefficient	(1)	(2)
constant	0.285	0.524
	(0.00104)	(0.00122)
endogenous renegotiation	0.192	0.123
	(0.00147)	(0.00107)
average haircut		-0.00637
		(2.49e-05)
default probability		0.000534
		(8.42e-05)
average spread		0.000529
		(1.59e-05)
debt-to-GDP ratio		0.000397
		(3.61e-06)
Observations	100,800	100,800
R^2	0.145	0.692

Note: Robust standard errors in parentheses.

Column (1) of Table 8 shows a regression of the probability of an interest rate hike triggering a default on a dummy that takes the value equal to 1 if the model generating the data exhibits endogenous renegotiation and 0 if it exhibits a fixed haircut. As expected, the coefficient is the same as the difference between the two means of the distributions plotted in Figure 10. Column (2) of the table shows the same regression when we add as controls the moments generated by the model. We control for the four moments that we targeted in our calibrations in Table 3: the average haircut, the default probability, the average spread, and the debt-to-GDP ratio. As expected, all t-statistics are very high, and the fit of the regression increases substantially. The interpretation of the second coefficient in Column (2) is that conditional on targeting the same moments, the probability of a Volcker shock triggering a default event is 12.3 percent higher with a model that features endogenous renegotiation (as opposed to one with fixed haircuts). This number is between the differences of 0.09 and 0.16 that we obtained using the calibration for Mexico for the two values of θ, the arrival probability of renegotiation opportunities (see Table 6).

6 Conclusion

In this paper, we develop a theory of sovereign default and debt renegotiation in which shocks to risk-free interest rates affect default incentives through a standard mechanism and a renegotiation mechanism. We find that the renegotiation mechanism substantially increases the probability of a default following an increase in the risk-free rate, relative to a model with the standard mechanism alone. Thus, we argue, the renegotiation mechanism we study supports the widespread narrative that the Volcker shock was a sufficient factor in the series of defaults that started with Mexico in 1982.

We have made assumptions on the expectations of the Mexican government when it defaulted in August 1982 that imply that it expected a rapid renegotiation of its debt using Nash bargaining as in Binmore, Rubinstein, and Wolinsky (1986). The empirical results in Section II suggest that the government would have expected lenders to be more anxious to negotiate when the risk-free rate was high in a wide variety of negotiation games, even in those where the government would expect some delays in settlement. In the data from Asonuma, Niepelt and Ranciere (2023) the correlation between time to settlement and the risk-free rate is -0.29, suggesting that lenders facilitate rapid renegotiation when the risk-free rate is high. This is an interesting topic for future research.

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A Haircut measures

Following Federico Sturzenegger and Jeromin Zettelmeyer (2008), the haircut for a debt instrument i exchanged for another instrument e is:

$$h_{i,e}^{SZ} = 1 - \frac{NPV(r_e, x_e)}{NPV(r_e, x_i)}, \tag{27}$$

where $NPV(r,x)$ is the net present value of the cash flow stream of a debt instrument discounted at a rate r and x is a vector of the instrument's face value, maturity, and coupon structure.

An important difference between the model and the data is that haircuts in the data consider changes to the face value of the debt, its maturity, and its coupon structure, while in the model, only the face value b is renegotiated, and the maturity rate γ and coupon structure are fixed. Therefore, for each haircut observed in the data, we calculate its model equivalent, which considers our simplifying assumptions and benchmark calibration.

Consider an instrument i with face value b_i. Let $\gamma_{i,t}$ be its maturity rate in period t and $z_{i,t}$ its coupon rate. In the data, the net present value of the cash flow from instrument i discounted at the exit rate r_e is

$$NPV^d\left(r_e, x_i^d\right) = \sum_{t=0}^{\infty} \left(\frac{1}{1+r_e}\right)^t \left[\prod_{s=0}^{t} \left(1-\gamma_{i,s}\right)\right] \left[\gamma_{i,t} + z_{i,t}\left(1-\gamma_{i,t}\right)\right] b_i, \tag{28}$$

where $x_i^d = \left(b_i, \gamma_{i,0}, \gamma_{i,1}, \ldots, z_{i,0}, z_{i,1}, \ldots\right)$. In the model, $\gamma_{i,t} = \gamma$ and $z_{i,t} = 0$, for all i,t, are fixed parameters, so the analogous expression is

$$NPV^m\left(r_e, x_i^m\right) = \sum_{t=0}^{\infty} \left(\frac{1-\gamma}{1+r_e}\right)^t \gamma b_i = \gamma b_i \frac{1+r_e}{\gamma + r_e}, \tag{29}$$

where $x_i^m = (b_i, \gamma)$. When debt is renegotiated in the model, for a given income and risk-free rate (y,r), the net present value of the cash flow stream of renegotiated debt b^R is

$$NPV^m\left(r_e, \left(b^R, \gamma\right)\right) = \gamma b^R + q^R(1-\gamma)b^R = \gamma b^R \frac{1+r^e}{\gamma + r^e}, \tag{30}$$

where $q^R = q\left(b^P\left(b^R(y,r), y, r\right)\right)$ and r^e is an exit yield that makes the second equality hold. Thus, the SZ-haircut in the model is

$$h^{SZm} = 1 - \frac{\gamma b^R \frac{1+r^e}{\gamma+r^e}}{\gamma b \frac{1+r^e}{\gamma+r^e}} = 1 - \frac{b^R}{b}, \tag{31}$$

which is simplified significantly by the fact that both streams are discounted by the same r^e and that the maturity rate remains unchanged. In the data, the losses incurred by lenders come from changes to maturity and coupon structures, as well as changes to the face value of the debt. In the model, all losses are captured by the change from b to b^R.

Given data for r_e for each restructured instrument, and given our calibrated value $\gamma = 0.75$, we compute a model face value b_i, for each observed $NPV^d\left(r_e, x_i^d\right)$, by combining equations (28) and (29):

$$NPV^d\left(r_e, x_i^d\right) = \gamma b_i \frac{1+r_e}{\gamma + r_e}, \tag{32}$$

which is the face value that would generate the same $NPV^d\left(r_e, x_i^d\right)$ if the instrument had the model's maturity and coupon structures and the future risk captured by r_e remained unchanged.

B Robustness, evidence

Table 9 presents the estimation of a regression equation using SZ-haircuts as a dependent variable. This table shows that the positive relationship between haircuts and interest rates remains positive and statistically significant in all specifications with the relevant controls considered by Tamon Asonuma, Dirk Niepelt and Romain Ranciere (2023): the remaining time to maturity at the time of the exchange, the coupon rate of the instrument if it is fixed, and an indicator variable for whether the instrument has a floating coupon rate. Each additional percentage point in risk-free rates increases haircuts by between 6 and 7 percentage points.

Table 10 presents the estimation using the model-equivalent haircuts as a dependent variable. The same level of robustness is maintained in our findings when using the alternative measure of haircuts, which incorporates the simplifying assumptions inherent to our model: fixed maturity and coupon structure. The estimated effect of risk-free rates on our measure of model haircuts is slightly stronger, with a magnitude between 6.8 and 7.6 percentage points. Indeed, for each specification, the regression using the model haircuts estimates a higher effect of the real risk-free

Table 9: Regression results with SZ-haircuts

	Without controls	With controls		
	(1)	(2)	(3)	(4)
real risk-free rate	7.030	7.015	6.510	6.329
	(2.951)	(3.039)	(3.609)	(3.800)
maturity of instrument (years)		0.0960	-0.232	-0.225
		(0.0813)	(0.106)	(0.107)
coupon rate (fixed, percent)			0.939	1.091
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coupon rate (float, dummy)				1.914
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constant	37.06	36.53	36.36	35.29
	(5.196)	(5.367)	(6.284)	(6.965)
Observations	139	139	78	78
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Table 10: Regression results with model haircuts

	Without controls	With controls		
	(1)	(2)	(3)	(4)
real risk-free rate	7.602	7.535	7.117	6.807
	(3.484)	(3.592)	(3.746)	(3.966)
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	(6.051)	(6.268)	(6.683)	(7.468)
Observations	94	94	75	75
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Episode random effects	Yes	Yes	Yes	Yes

Note: Standard errors in parentheses.

C Robustness, model

Table 11 presents our main results for two alternative versions of the model in which debt is not as easy to adjust as in our benchmark. In the first case, we add an ad-hoc exogenous adjustment cost to the debt. We consider the following quadratic cost

$$\psi\left(b', b\right) = \frac{\phi}{2}\left(b' - b\right)^2, \tag{33}$$

where we choose $\phi = 5.5$ so that the standard deviation of the current account is roughly half of what it is in the benchmark case with no adjustment cost.[7]

In the second, we choose a substantially higher risk aversion coefficient $\sigma = 10$ so as to make adjustments in consumption—and therefore on the debt—more costly. For this case we recalibrate the default penalty parameters because otherwise the targeted moments vary substantially across models.

[7]The standard deviation of the current account as a fraction of GDP is 2 percent in the data, which is already larger than its value of 1.2 percent in the benchmark model with no adjustment cost. The other simulated moments do not vary significantly with different values for this adjustment cost.

Table 11: Probability of default conditional on a Volcker shock

	No renegotiation, no recovery	Fixed exogenous haircut	Endogenous renegotiation
benchmark	0.05	0.12	0.21
with adjustment cost	0.04	0.11	0.22
with $\sigma = 10$	0.04	0.11	0.20

D Exchange rate channel

Following a suggestion of a referee, this appendix studies the robustness of our main results to the introduction of an exchange rate channel. We consider a third, indirect channel through which a Volcker shock can affect the probability of default in countries that borrow in U.S. dollars.

Imagine if, as several papers in the literature argue, an increase in the U.S. risk-free interest rate conveys a depreciation of the domestic currency of the borrowing country. If an important fraction of the debt is denominated in dollars, this increases the real burden of debt service in units of domestic output, providing an additional incentive to default beyond the two mechanisms already identified in the paper.

D.1 Model

To accommodate this effect in a mechanical way, we consider a single modification to the model in the paper. Specifically, we augment the government's budget constraint in the repayment problem so as to reflect the real exchange rate depreciation that accompanies a transition to the high interest rate regime. All other equilibrium conditions—the value of defaulting, the Nash bargaining problem that determines the renegotiated debt level, the value of holding defaulted bonds, and the bond pricing equation—are unchanged.

Specifically, we assume that when the risk-free interest rate transits from the low regime r_L to the high regime r_H, the real value of outstanding debt obligations and new bond issuance are scaled up by a factor $(1+\Delta)$, where $\Delta \geq 0$ is a parameter that captures the magnitude of the depreciation. The scaling reverses when the interest rate transitions back from r_H to r_L. The parameter $\Delta = 0$ nests the benchmark model of the paper as a special case.

Government's problem. The value function of the government in good financial standing is:

$$V(b,y,r) = \max_{d\in\{0,1\}} \Big\{(1-d)\, V^P(b,y,r) + d\, V^D(y,r)\Big\}, \tag{34}$$

where $d = 1$ denotes default. The value of repayment solves:

$$V^P(b,y,r) = \max_{c,b'} \Big\{u(c) + \beta \mathbb{E}\big[V(b',y',r')\big]\Big\}, \tag{35}$$

subject to the budget constraint, which now depends on the interest rate regime:

$$r = r_L: \quad c + \gamma b \;=\; y + q^P(b',y,r)\big[b' - (1-\gamma)b\big], \tag{36}$$

$$r = r_H: \quad c + \gamma b\,(\mathbf{1}+\boldsymbol{\Delta}) \;=\; y + q^P(b',y,r)\,(\mathbf{1}+\boldsymbol{\Delta})\big[b' - (1-\gamma)b\big]. \tag{37}$$

The term $(\mathbf{1}+\boldsymbol{\Delta})$ appears in bold to highlight the modification relative to the benchmark model. When $r = r_H$, the government must service its existing debt at the higher cost $\gamma b\,(1+\Delta)$ rather than γb, and the proceeds from issuing new bonds are also scaled by $(1+\Delta)$, reflecting the higher peso value of dollar-denominated issuance. The two effects partially offset each other. An increase in Δ tightens the budget constraint when debt service exceeds issuance proceeds, that is, when $\gamma b > q^P(b',y,r)\big[b' - (1-\gamma)b\big]$, so that repayment becomes less attractive relative to default.

The value of defaulting, $V^D(y,r)$, the bond price schedule $q^P(b',y,r)$, the renegotiation outcome $b^R(y,r)$, and the value of holding defaulted bonds $Q^D(y,r)$ are all defined exactly as in equations (16)–(19) of the paper and are unchanged by this modification. The exchange rate channel therefore operates exclusively through the repayment budget constraint.

Model with fixed haircuts. The same budget constraint modification applies to the fixed-haircut counterfactual models. Upon a renegotiation opportunity, the government re-enters financial markets with debt $b^R = (1-\kappa)b$, as in the paper, and the budget constraint in repayment takes the same form as equations (36)–(37) above.

Calibration. We do not recalibrate the model for each value of Δ. Our purpose is to conduct a comparative statics exercise that isolates the contribution of the exchange rate channel, holding all other parameters fixed at the values in Table 3 of the paper. For $\Delta > 0$, the model will therefore not exactly reproduce the four calibration targets of the benchmark, but this exercise cleanly identifies how the revaluation of the debt burden amplifies the probability of a Volcker shock triggering a default across model variants.

D.2 Results

Figure 11 reports the probability of an interest rate hike triggering a default, $\xi = \Pr(d_t = 1 \mid d_{t-1} = 0, r_t = r_H, r_{t-1} = r_L)$, as a function of Δ across the different model specifications: endogenous renegotiation, fixed haircuts, and no renegotiation. We focus on the benchmark renegotiation probability ($\theta = 0.19$) and report both the benchmark parameterization and the version with debt adjustment costs. The horizontal axis runs from $\Delta = 0$ (the benchmark model) to $\Delta = 0.20$.

The main finding is that the renegotiation mechanism is robust to the introduction of the exchange rate channel. For any given Δ, the endogenous renegotiation model generates a substantially higher default probability following a Volcker shock than the fixed-haircut and no-recovery counterfactuals. These results confirm that the renegotiation mechanism identified in the paper is not an artifact of abstracting from the exchange rate channel, and that both channels operate as complementary amplifiers of the effect of interest rate shocks on default incentives.

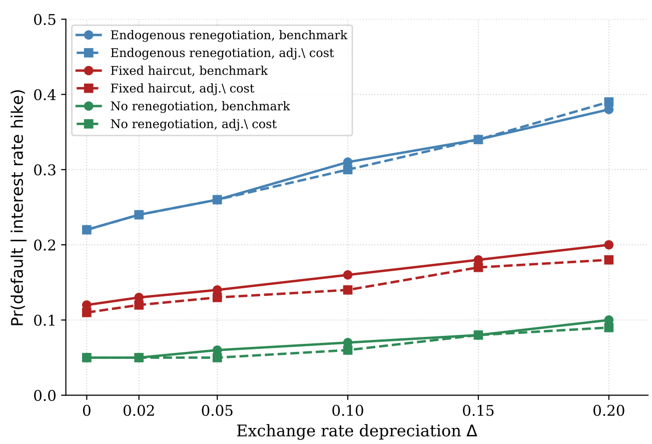

Figure 11: Probability of a Volcker shock triggering a default as a function of the exchange rate depreciation Δ

Note: We set the renegotiation probability $\theta = 0.19$ for both the benchmark model (solid lines) and the one with adjustment cost of changing the debt (dashed lines). The blue lines correspond to the model with endogenous renegotiation, the red lines to the model with exogenous haircuts, and the green lines to the no-renegotiation benchmark. All parameters other than Δ are held fixed at their benchmark values from Table 3 of the paper.

A Haircut measures

Following Federico Sturzenegger and Jeromin Zettelmeyer (2008), the haircut for a debt instrument i exchanged for another instrument e is:

$$h_{i,e}^{SZ} = 1 - \frac{NPV\left(r_e, x_e\right)}{NPV\left(r_e, x_i\right)}, \tag{A1}$$

where $NPV\left(r, x\right)$ is the net present value of the cash flow stream of a debt instrument discounted at a rate r and x is a vector of the instrument's face value, maturity, and coupon structure.

An important difference between the model and the data is that haircuts in the data consider changes to the face value of the debt, its maturity, and its coupon structure, while in the model, only the face value b is renegotiated, and the maturity rate γ and coupon structure are fixed. Therefore, for each haircut observed in the data, we calculate its model equivalent, which considers our simplifying assumptions and benchmark calibration.

Consider an instrument i with face value b_i. Let $\gamma_{i,t}$ be its maturity rate in period t and $z_{i,t}$ its coupon rate. In the data, the net present value of the cash flow from instrument i discounted at the exit rate r_e is

$$NPV^d\left(r_e, x_i^d\right) = \sum_{t=0}^{\infty}\left(\frac{1}{1+r_e}\right)^t\left[\prod_{s=0}^{t}\left(1-\gamma_{i,s}\right)\right]\left[\gamma_{i,t} + z_{i,t}\left(1-\gamma_{i,t}\right)\right]b_i, \tag{A2}$$

where $x_i^d = \left(b_i, \gamma_{i,0}, \gamma_{i,1}, \ldots, z_{i,0}, z_{i,1}, \ldots\right)$. In the model, $\gamma_{i,t} = \gamma$ and $z_{i,t} = 0$, for all i, t, are fixed parameters, so the analogous expression is

$$NPV^m\left(r_e, x_i^m\right) = \sum_{t=0}^{\infty}\left(\frac{1-\gamma}{1+r_e}\right)^t \gamma b_i = \gamma b_i \frac{1+r_e}{\gamma + r_e}, \tag{A3}$$

where $x_i^m = \left(b_i, \gamma\right)$. When debt is renegotiated in the model, for a given income and risk-free rate $\left(y, r\right)$, the net present value of the cash flow stream of renegotiated debt b^R is

$$NPV^m\left(r_e, \left(b^R, \gamma\right)\right) = \gamma b^R + q^R\left(1-\gamma\right)b^R = \gamma b^R \frac{1+r^e}{\gamma + r^e}, \tag{A4}$$

where $q^R = q\left(b^P\left(b^R\left(y, r\right), y, r\right)\right)$ and r^e is an exit yield that makes the second equality hold. Thus, the SZ-haircut in the model is

$$h^{SZm} = 1 - \frac{\gamma b^R \frac{1+r^e}{\gamma + r^e}}{\gamma b \frac{1+r^e}{\gamma + r^e}} = 1 - \frac{b^R}{b}, \tag{A5}$$

which is simplified significantly by the fact that both streams are discounted by the same r^e and that the maturity rate remains unchanged. In the data, the losses incurred by lenders come from changes to maturity and coupon structures, as well as changes to the face value of the debt. In the model, all losses are captured by the change from b to b^R.

Given data for r_e for each restructured instrument, and given our calibrated value $\gamma = 0.75$, we compute a model face value b_i, for each observed $NPV^d\left(r_e, x_i^d\right)$, by combining equations (A2) and (A3):

$$NPV^d\left(r_e, x_i^d\right) = \gamma b_i \frac{1+r_e}{\gamma + r_e}, \tag{A6}$$

which is the face value that would generate the same $NPV^d\left(r_e, x_i^d\right)$ if the instrument had the model's maturity and coupon structures and the future risk captured by r_e remained unchanged.

B Robustness, evidence

Table B1 presents the estimation of a regression equation using SZ-haircuts as a dependent variable. This table shows that the positive relationship between haircuts and interest rates remains positive and statistically significant in all specifications with the relevant controls considered by Tamon Asonuma, Dirk Niepelt and Romain Ranciere (2023): the remaining time to maturity at the time of the exchange, the coupon rate of the instrument if it is fixed, and an indicator variable for whether the instrument has a floating coupon rate. Each additional percentage point in risk-free rates increases haircuts by between 6 and 7 percentage points.

Table B2 presents the estimation using the model-equivalent haircuts as a dependent variable. The same level of robustness is maintained in our findings when using the alternative measure of haircuts, which incorporates the simplifying assumptions inherent to our model: fixed maturity and coupon structure. The estimated effect of risk-free rates on our measure of model haircuts is slightly stronger, with a magnitude between 6.8 and 7.6 percentage points. Indeed, for each specification, the regression using the model haircuts estimates a higher effect of the real risk-free

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	Without controls	With controls		
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In the second, we choose a substantially higher risk aversion coefficient $\sigma = 10$ so as to make adjustments in consumption—and therefore on the debt—more costly. For this case we recalibrate the default penalty parameters because otherwise the targeted moments vary substantially across models.

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$$V^P(b,y,r) = \max_{c,\, b'} \Big\{ u(c) + \beta \mathbb{E}\big[V(b',y',r') \big] \Big\}, \tag{D2}$$

subject to the budget constraint, which now depends on the interest rate regime:

$$r = r_L: \quad c + \gamma b \;=\; y + q^P(b',y,r)\big[b' - (1-\gamma)b\big], \tag{D3}$$

$$r = r_H: \quad c + \gamma b\,(\mathbf{1}+\boldsymbol{\Delta}) \;=\; y + q^P(b',y,r)\,(\mathbf{1}+\boldsymbol{\Delta})\big[b' - (1-\gamma)b\big]. \tag{D4}$$

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Figure D1 reports the probability of an interest rate hike triggering a default, $\xi = \Pr(d_t = 1 \mid d_{t-1} = 0, r_t = r_H, r_{t-1} = r_L)$, as a function of Δ across the different model specifications: endogenous renegotiation, fixed haircuts, and no renegotiation. We focus on the benchmark renegotiation probability ($\theta = 0.19$) and report both the benchmark parameterization and the version with debt adjustment costs. The horizontal axis runs from $\Delta = 0$ (the benchmark model) to $\Delta = 0.20$.

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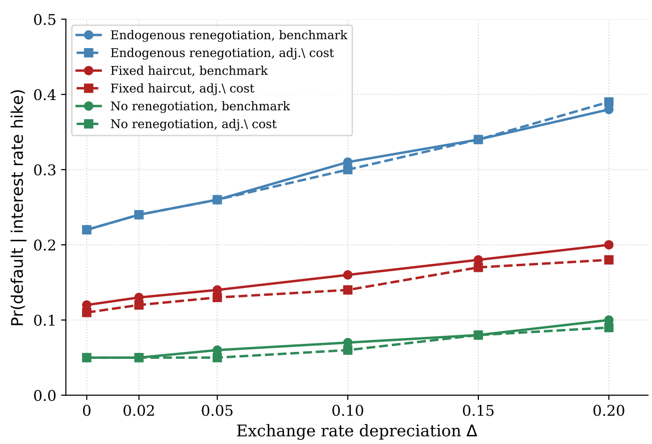

Figure D1: Probability of a Volcker shock triggering a default as a function of the exchange rate depreciation Δ

Note: We set the renegotiation probability $\theta = 0.19$ for both the benchmark model (solid lines) and the one with adjustment cost of changing the debt (dashed lines). The blue lines correspond to the model with endogenous renegotiation, the red lines to the model with exogenous haircuts, and the green lines to the no-renegotiation benchmark. All parameters other than Δ are held fixed at their benchmark values from Table 3 of the paper.

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