FX Interventions in a Small Open Economy: The Case of Domestic Non-Deliverable Forwards*

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Abstract

We study how central banks can use foreign exchange forwards to stabilize exchange rates and support financial stability, using the Bank of Mexico's introduction of domestic non-deliverable forwards (DNDFs) in 2017. Across announcements of the policy intervention, option implied volatility fell by 0.38 percentage points, with larger effects at shorter maturities. Announcements also reduced the risk-neutral probability of large depreciations, while the implementation of the policy via auctions had no significant effects. We rationalize these findings in a small open economy with collateral constraints and self-fulfilling currency crises. The central bank's provision of insurance against future depreciation through DNDFs dampens the feedback between depreciation and deleveraging in self-fulfilling crises by sustaining external debt and supporting collateral values. Anticipation of DNDF interventions appreciates the currency and reduces exchange rate risk before the contracts are issued. Quantitatively, DNDFs generate larger welfare gains than macroprudential taxes on external debt in states with high debt.

JEL classification: E44, E58, F31, F41, G14, H23
Keywords: FX intervention, Non-deliverable forwards, Self-fulfilling crisis

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1 Introduction

Central banks with flexible exchange rates can face self-fulfilling depreciations. Market participants may sell domestic currency because they expect others to sell, reinforcing a depreciation even without a deterioration in fundamentals. Selling foreign reserves can relieve exchange rate pressure, but a visible reserve drawdown may also weaken confidence in the central bank's capacity to intervene. The possibility that reserve sales invite further pressure creates a difficulty for central banks seeking to stabilize the foreign exchange market.

Central banks also intervene by supplying currency hedges through swaps and forwards (Patel and Cavallino, 2019). Brazil's exchange rate swaps and Mexico's domestic non-deliverable forwards are examples of contracts settled in domestic currency. Domestic currency settlement allows the central bank to protect private agents against depreciation without delivering dollar reserves. The programs aim to support liquidity and facilitate orderly trading in the foreign exchange market. Assessing the programs, therefore, requires examining future exchange rate risk as well as the immediate response of the currency.

This paper studies whether a central bank can stabilize a floating currency by committing to supply insurance against depreciation. We examine Mexico's introduction of domestic non-deliverable forwards (DNDFs) in 2017, distinguishing the market response to policy announcements from the response to subsequent auctions. We then develop a model in which insurance lowers future crisis risk, encouraging current lending and borrowing while appreciating the currency at the time of the announcement. The model also allows us to compare forward insurance with a tax on new external borrowing.

On February 21, 2017, following the peso's depreciation and elevated volatility after the 2016 U.S. election, Mexico's Foreign Exchange Commission announced that the Bank of Mexico would auction DNDFs to domestic financial intermediaries. A DNDF settles the difference between the realized exchange rate and the contracted forward rate in pesos. The central bank pays the counterparty when the peso depreciates beyond the forward rate and receives payment when the peso is stronger than the forward rate. Settlement requires no delivery of dollars. However, central bank losses must still be financed. Reserve accumulation had flattened after the decline in oil revenues and changes in the arrangements governing dollar transfers to the central bank. The peso settlement provision allowed the authorities to offer insurance without drawing down foreign reserves.

Our central empirical finding is a decline in option implied exchange rate volatility around the program's announcements. Regressions using daily option data estimate an average decline across maturities of approximately 0.33 to 0.38 percentage points. The reduction is generally larger at short maturities, indicating that the change in the market's valuation of exchange rate risk was concentrated at shorter horizons. The peso also appreciated at the announcements. An intraday event study estimates an appreciation of approximately 0.33

pesos per dollar at the first announcement, with smaller movements at later announcements.

The estimated auction effects on the spot exchange rate and implied volatility are not statistically significant. The intraday evidence places the spot response at the announcements before the associated contracts were allocated. The timing is consistent with market participants responding to the anticipated insurance provision. Once the availability of insurance is anticipated, an auction may convey little additional information.

We also recover risk-neutral depreciation probabilities from option prices at different strikes. At the first announcement, the probability that the peso ends more than five percent weaker than the forward rate falls across maturities, with a decline of about 1.28 percentage points at the one-month horizon. The decline remains when the fitted option smile incorporates asymmetry and curvature, and the accompanying regressions suggest that the overall fall in volatility accounts for much of the reduction in tail risk.

Our synthetic control estimation at a weekly frequency also finds a decline in implied volatility relative to other currencies. Monthly surveys of private sector specialists show a decline after February 2017 in the share citing exchange rate movements as a major obstacle to growth, together with a downward revision in exchange rate forecasts. The survey changes are consistent with the announcement response in financial markets.

To explain how lower future crisis risk can appreciate the currency today, we introduce central bank forwards into a small open economy with collateral constraints, downward nominal wage rigidity, and risk-averse financial intermediaries. The model builds on Schmitt-Grohé and Uribe (2021) and Bianchi and Coulibaly (2026). Intermediaries fund domestic currency loans with dollar debt and therefore bear exchange rate risk. Households' borrowing capacity depends on income from tradable endowments and nontradable production. Pessimistic expectations can induce deleveraging and reduce spending on nontradables. Lower employment and a weaker currency reduce the dollar value of nontradable income, tightening borrowing constraints and validating the anticipated deleveraging.

We first study the settlement of previously issued DNDFs in a deterministic economy. Payments to intermediaries in depreciation states support private consumption and the nontradable income that serves as collateral. For a given private continuation allocation, greater insurance coverage raises the equilibrium borrowing limit. The deterministic examples show that insurance can eliminate crisis equilibria over a range of initial debt and increase borrowing in the worst equilibrium when a crisis remains possible. A tax rule contingent on aggregate borrowing can also eliminate crisis equilibria in the deterministic setting.

We then conduct a quantitative analysis of an optimal temporary DNDF program and compare it to the effects of optimal capital control taxes. The central bank begins with zero assets and chooses a forward rate after observing fundamentals but before the realization of the nonfundamental shock that selects the equilibrium. Intermediaries then choose how much of their borrowing to insure. Contracts settle in the following period, and the central

bank closes any surplus or deficit through a household transfer or tax one period later. The central bank can borrow to finance settlement in the meantime.

On average, DNDF payments sharply reduce crisis risk and exchange rate volatility in the settlement period. The prospect of insurance payments and a lower risk of crisis at repayment improves current lending conditions. Higher household borrowing and consumption then appreciate the currency and support collateral values. At the announcement, the expected exchange rate in the issuance period appreciates by 2.82% on average relative to laissez faire. After coverage expires, the additional private debt and fiscal burden raise crisis risk above laissez faire. The program thus protects the economy during the insured period at the cost of greater vulnerability afterward.

The capital control tax reduces future currency risk by limiting current borrowing and spending, which depreciates the currency upon impact. On average, the tax yields larger welfare gains than forward insurance. The ranking reverses in the three high-debt states examined in the quantitative analysis, where the borrowing constraint binds even under normal expectations. DNDFs implement full employment under normal expectations, although the borrowing constraint remains binding and a severe depreciation is still possible under pessimistic expectations. After accounting for future fiscal costs, expected lifetime welfare gains are equivalent to raising consumption by approximately 10 to 19% over the three policy periods. The optimal capital control tax is zero in all three states. Forward insurance is valuable in these states because anticipated protection against depreciation sustains lending when high debt passed on from the previous period restricts consumption and employment.

Literature Review This paper contributes to three strands of literature. First, we extend the empirical literature on foreign exchange intervention by documenting the exchange rate effects of announced insurance provision. Menkhoff (2013) and Fratzscher et al. (2019) document how intervention effectiveness varies with market conditions and policy design. Chamon et al. (2017), Garcia and Volpon (2014), and Macalós (2023) examine Brazil's swaps settled in local currency, which serve as an institutional counterpart to Mexico's DNDFs. We provide evidence from Mexico on spot exchange rates, implied volatility, and risk-neutral depreciation probabilities across maturities. The distinction between announcements and subsequent auctions shows that the currency appreciates and the market valuation of future depreciation risk falls before the associated contracts are allocated.

Using Brazilian data on bank credit, foreign funding, and employment, Gonzalez et al. (2026) show that the central bank's FX hedging attenuated the contraction in domestic lending associated with global financial shocks. We complement the evidence on credit with evidence on how anticipated insurance provision affects current exchange rates and future depreciation risk. Our model explains how a lower risk of crisis at repayment sustains current lending and appreciates the currency upon announcement.

Second, we contribute to theories of foreign exchange intervention by explaining how

insurance against future depreciation affects the current exchange rate through lending and collateral values. Sarno and Taylor (2001) review portfolio balance, signaling, and coordination channels. Gabaix and Maggiori (2015) show how financiers' limited risk-bearing capacity affects exchange rates, while Cavallino (2019) and Fanelli and Straub (2021) study optimal intervention when limits to international arbitrage allow central bank trades to affect exchange rates.[1] Reitz and Taylor (2008) examine how intervention can coordinate stabilizing trades when exchange rates depart from fundamentals. In our model, forward settlements sustain consumption and collateral values in depreciation states, reducing crisis risk at repayment. Anticipated protection improves current lending conditions and raises borrowing and consumption, appreciating the currency before settlement.

Third, we contribute to the literature on self-fulfilling financial crises by evaluating the effects of the central bank's forward provisions to reduce exchange rate risk. Obstfeld (1996) studies how speculative pressure and the government's incentive to defend a peg can generate self-fulfilling currency crises. Morris and Shin (1998) show how noisy private information can select a unique outcome in a currency attack model. Jeanne and Rose (2002) study how endogenous noise trading links exchange rate regimes to nonfundamental volatility. Bocola and Dovis (2019) use sovereign spreads and debt maturity choices to quantify self-fulfilling debt crises. We combine evidence from currency options with a model in which a commitment to depreciation insurance alters private borrowing and crisis outcomes without committing to defend a particular spot exchange rate.

Our analysis of crisis prevention builds on Schmitt-Grohé and Uribe (2021) and Bianchi and Coulibaly (2026), who show how the interaction of borrowing and collateral values can generate self-fulfilling crises. Davis et al. (2023) study how reserve accumulation and sales can prevent sudden stops when deleveraging depresses collateral values. We introduce forward insurance settled in domestic currency and assess the welfare gains after accounting for additional private borrowing and future fiscal costs. We show that protection during the insured period comes with a greater crisis risk after coverage expires. The comparison with a capital control tax shows why insurance can be more valuable when the economy is heavily indebted.

Outline Section 2 describes the DNDF program and presents the empirical evidence. Section 3 develops the model. Section 4 analyzes self-fulfilling equilibria and compares forward insurance with a capital control tax in the deterministic economy. Section 5 evaluates the exchange rate, crisis risk, and welfare effects of both policies in the stochastic economy. Section 6 concludes.

[1] The portfolio balance channel operates when domestic and foreign assets are imperfect substitutes, so that a sterilized intervention changes their relative supplies and moves the exchange rate through the risk premium; the signaling channel operates through expectations, as intervention conveys information about future monetary policy or fundamentals; and the coordination channel, through which intervention resolves a coordination failure among market participants.

2 DNDF Program and Empirical Evidence

A DNDF provides insurance precisely when the peso depreciates. A commitment to supply such insurance can therefore change how market participants value future currency risk before any contract is allocated. We examine this response through option implied volatility and risk-neutral depreciation probabilities, together with the immediate movement in the spot exchange rate. Comparing announcements with the auctions of this instrument helps distinguish the arrival of news about future protection from the implementation of that commitment. We begin by documenting the pressures on the Mexican peso and the limits to reserve accumulation that made domestic currency settlement attractive, and then turn to the market response.

2.1 Reserve Accumulation and Pressure on the Peso

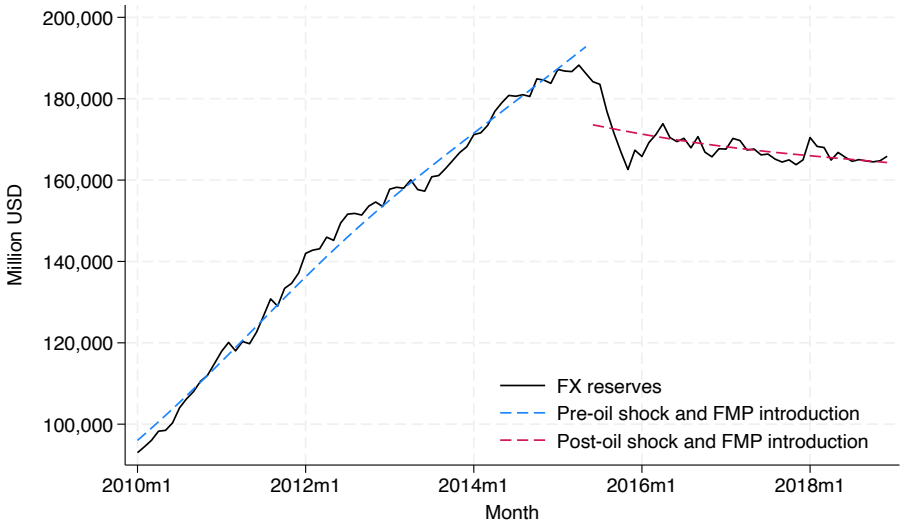


FIGURE 1. Bank of México's FX reserves evolution

Note: Own elaboration with data from Banco de México. Time series only includes foreign currency reserves excluding IMF reserve position, financial derivatives, gold, and other. Blue and red dashed lines represent the trend estimated via an HP filter with $\lambda = 14,400$.

Figure 1 shows a structural change in the dynamics of Mexico's international reserves around 2015. Between 2010 and mid-2014, reserves increased steadily, reflecting foreign currency inflows from oil exports and the institutional arrangement whereby U.S. dollar revenues from *Petróleos Mexicanos* (Pemex) were regularly sold to Banco de México and accumulated as reserves. This trend reversed after the collapse in global oil prices from mid-2014. The energy reform of 2013 and 2014 created the Fondo Mexicano del Petróleo (FMP), which began operating in 2015, and rerouted hydrocarbon revenues through the oil fund before transferring them to the federal government, altering the mechanism through which foreign exchange proceeds reach the central bank's balance sheet. The central bank

was also drawing on reserves directly during this period. Following the depreciation, the Foreign Exchange Commission sold dollars through an auction mechanism introduced in late 2014, which was expanded in 2015, and conducted a discretionary intervention in February 2016. Together with the slowdown in inflows, these sales ended the steady accumulation of reserves and drew the stock down from a peak of about 196 billion dollars in early 2015 to roughly 177 billion by the end of the year (for more details, see Fondo Mexicano del Petróleo (2015), Banco de México (2016), International Monetary Fund (2015)). These developments help explain why the central bank preferred an instrument that could defend the exchange rate without drawing down reserves. With the reserve stock no longer growing and already drawn down in defense of the peso, and with the authorities wary that a further visible drawdown could itself signal weakness and invite speculative pressure, the central bank had a strong reason to prefer a tool that provides insurance against exchange rate depreciation without spending reserves.

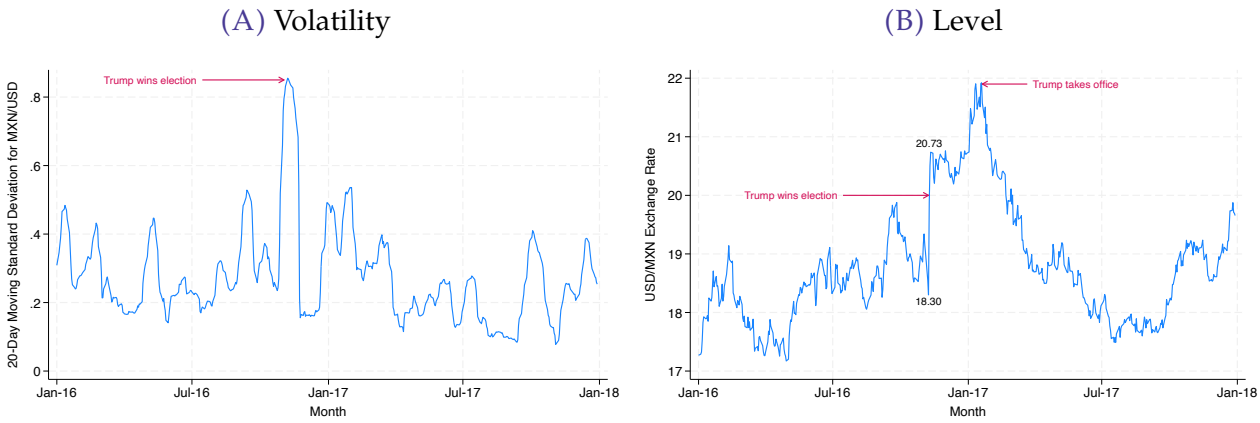


FIGURE 2. USD/MXN Exchange Rate Volatility and Level

Note: Own elaboration with Bloomberg and WSJ data. An increase in the level represents a depreciation of the peso. Volatility is the 20-day rolling standard deviation.

Following the 2016 U.S. presidential election and the ensuing political pressure, the peso experienced a period of elevated volatility and downward pressure. Figure 2A plots the 20-day rolling standard deviation of the USD/MXN exchange rate. Volatility jumped after the election and spiked again when President Trump took office in late January 2017. The peso had experienced a comparable spike in volatility only during the Global Financial Crisis of 2008 and 2009. Figure 2B shows a 13.28% one-day depreciation on the election result and a peak near 22 pesos per dollar, one of the largest depreciations of the Mexican peso experienced in years.

On February 21, 2017, at approximately 2:14 pm, Mexico's Foreign Exchange Commission announced the DNDF program to be implemented by the Bank of Mexico. The announcement authorized up to USD 20 billion in coverage and scheduled an initial USD 1 billion auction for Monday, March 6, 2017. Subsequent announcements provided for additional auctions

of USD 4 billion on October 25, 2017 (9:00 am) and USD 500 million on December 26, 2017 (7:45 am), within the original program limit. A translation of the initial press release is in Appendix A. The separation between announcements and their associated auctions allows us to examine the response to the commitment before the insurance contracts were allocated.

2.2 What Is a DNDF, and Why Non-Deliverable?

A DNDF is "domestic" in that it is settled in domestic currency and "non-deliverable" in that only the difference between the forward rate and the realized spot rate changes hands (i.e., there is no exchange of US dollars at the end of the contract). Let f_t be the forward rate set at auction in period t (pesos per dollar), e_{t+h} the spot rate at settlement, and q_t the notional purchased. The insured agent receives

$$\text{Payment}_{t+h} = (e_{t+h} - f_t) \times q_t. \tag{1}$$

If the peso depreciates ($e_{t+h} > f_t$), the agent receives pesos from the central bank. If it appreciates, the agent pays pesos. For example, with $f_t = 18$, $q_t = 1{,}000{,}000$ dollars and $e_{t+h} = 19$, the central bank transfers 1,000,000 pesos.

Domestic currency settlement determines how the central bank meets its obligations. A deliverable currency forward exchanges the contracted currencies at maturity, whereas a DNDF settles their value difference in pesos. The latter, therefore, requires no delivery of dollars even when the peso depreciates substantially. It allows the central bank to provide exchange rate protection without an immediate reduction in its reserve stock. This feature does not make the insurance free. An unfavorable exchange rate realization creates a loss on the central bank's balance sheet, and credibility still depends on the resources available to absorb that loss. The advantage is that the capacity to honor the peso payment is not mechanically tied to the stock of foreign reserves. Given the reserve dynamics in Figure 1 and the authorities' concern about the information conveyed by reserve sales, this distinction helps explain the instrument's appeal. Domestic currency settlement also characterizes the Brazilian interventions studied by Gonzalez et al. (2026), Chamon et al. (2017), and Garcia and Volpon (2014).

2.3 Announcement Compressed Option Implied Volatility

If the commitment to insurance changes the market's assessment of future currency risk, that change should be reflected in option prices. Our central result concerns the option implied volatility of the USD/MXN exchange rate. Option implied volatilities are forward-looking measures of uncertainty about the future value of the underlying asset at a given horizon, recovered by inverting an option pricing formula (Dumas et al. (1998)). A higher implied

volatility means a wider range of anticipated outcomes (Kim and Kim (2003)). Because they price the distribution of the *future* exchange rate, their movement around an announcement is informative about changes in the market's assessment of risk in the near term.

To assess the impact of the announcements and implementations on option-implied volatilities across maturities, we estimate the following linear model using daily data from January 2016 to December 2017 on USD/MXN implied volatilities at maturities from 1 week to 1 year:

$$y_{i,t} = \alpha_i + \gamma t + \rho y_{i,t-1} + \omega_1 \mathbb{A}\{t = T_0\} + \omega_2 \mathbb{I}\{t = T_1\} + \boldsymbol{x}_t \boldsymbol{\beta} + \eta z_{t-1} + \varepsilon_{i,t}, \tag{2}$$

where $y_{i,t}$ is the implied volatility at maturity i and date t, α_i is a maturity fixed effect, $\mathbb{A}\{t = T_0\}$ and $\mathbb{I}\{t = T_1\}$ are indicators for the announcement and implementation dates, $\boldsymbol{x}_t$ are contemporaneous global controls (e.g., VIX, oil prices, daily change in the Fed funds rate), and z_{t-1} is the lagged daily change in Mexico's policy rate.

TABLE 1: Effect of DNDF Announcements and Auctions on Implied Volatility

Variable	Pooled			Panel		
	(1)	(2)	(3)	(4)	(5)	(6)
Lagged volatility	0.942***	0.929***		0.942***	0.929***	
	(0.020)	(0.021)		(0.032)	(0.032)	
Linear time trend	-0.0004***	-0.0001		-0.0004*	-0.0001	
	(0.0001)	(0.0002)		(0.0002)	(0.0003)	
Announcement	-0.325***	-0.373***	-0.380***	-0.324***	-0.372***	-0.380***
	(0.059)	(0.061)	(0.051)	(0.108)	(0.111)	(0.089)
Implementation	0.062	-0.043	0.018	0.062	-0.043	0.018
	(0.051)	(0.053)	(0.052)	(0.114)	(0.111)	(0.114)
Lagged Change Mon. Pol.		-0.005***	-0.007***		-0.005**	-0.007***
		(0.001)	(0.001)		(0.002)	(0.002)
VIX Index		0.050***	0.028***		0.050***	0.028**
		(0.008)	(0.007)		(0.013)	(0.013)
Oil Prices (WTI)		0.019***	0.010***		0.019***	0.010*
		(0.004)	(0.003)		(0.006)	(0.006)
Daily Change in Fed Funds Rate		0.003**	0.005***		0.003	0.005
		(0.002)	(0.002)		(0.003)	(0.003)
Fixed Effects				✓	✓	✓
Obs.	4,160	4,160	4,160	4,160	4,160	4,160
R^2	0.903	0.906	0.013	0.902	0.905	0.013

Note: The R^2 for the panel specifications is the within measure. ***, **, * denote significance at 1%, 5%, 10%. Pooled specifications use HAC-robust standard errors. Panel specifications use Driscoll and Kraay (1998) standard errors.

Pooling across maturities confirms the pattern (Table 1). The announcement lowered implied volatility by roughly 0.33 to 0.38 volatility points, statistically significant at the 1%

level across pooled and panel specifications and robust to global controls and maturity fixed effects. The implementation coefficient is economically small and never significant. The timing places the response at the arrival of news about the program before the associated insurance was allocated.

Estimating (2) separately by maturity yields Figure 3. At every maturity, implied volatility falls after an announcement, and the decline is larger the shorter the maturity, with the magnitude of the decline decreasing with maturity and leveling off beyond three months.[2] The announcement response is therefore concentrated in near-term exchange rate risk. This pattern is consistent with a reduction in the risk of an imminent self-fulfilling depreciation, although its maturity profile alone does not separate fundamental from nonfundamental uncertainty. By contrast, the auctions ($\hat{\omega}_2$) have no statistically significant effect at any maturity.

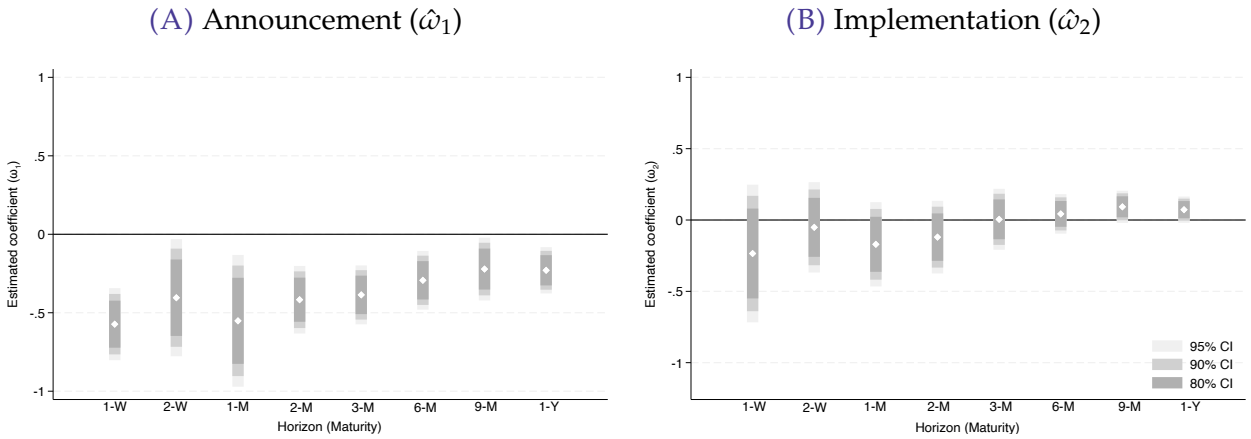


FIGURE 3. Effect of DNDF on Option Implied Volatility for USD/MXN, by Maturity

Note: Diamonds are point estimates of ω_i, $i = 1, 2$, from estimating (2) separately by maturity. Shaded areas are 80%, 90%, and 95% confidence intervals from HAC-robust standard errors.

2.4 Intraday Exchange Rate Responses

The reduction in expected currency risk was accompanied by an appreciation of the peso. This joint response is informative because a policy that supports financing can strengthen the currency today while protecting against future depreciation. To measure the immediate response separately from subsequent news, we use an intraday event study around each announcement and auction. Figure 4 plots the tick-by-tick USD/MXN rate from February 19 to March 7, 2017. At the instant of the announcement, the peso appreciated by approximately 40 cents and began a downward drift. The appreciation of about 53 cents on early March, for instance, coincides with public statements by Secretary of Commerce Wilbur Ross on NAFTA

[2]The pattern is consistent with Ederington and Lee (1996) and Kim and Kim (2003), who find that implied volatilities fall after macroeconomic announcements as uncertainty resolves. The ordering is nearly, though not perfectly, monotone: the 1-month contraction slightly exceeds the 2-week one.

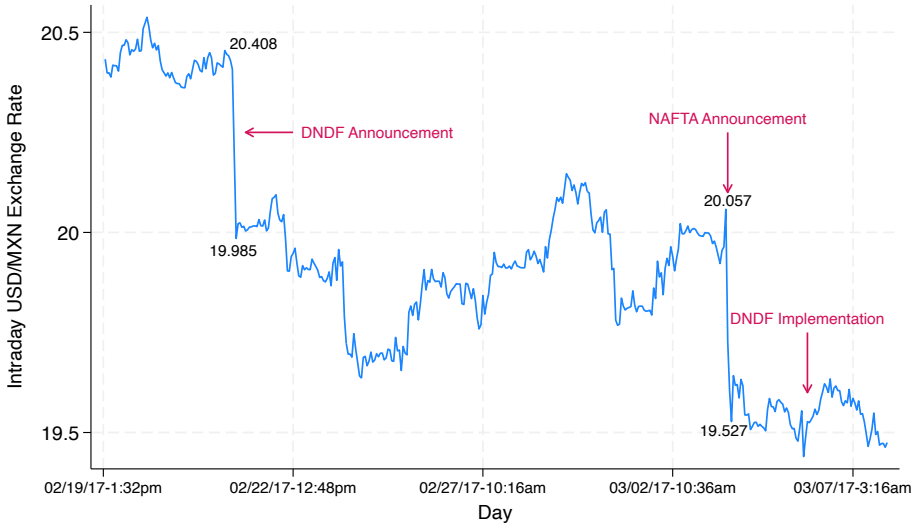


FIGURE 4. Intraday USD/MXN: First Announcement and First Auction

Note: Own elaboration with Bloomberg data. An increase is a depreciation of the peso. The announcement was at 2:14 pm on February 21, 2017. The first auction at 10:00 am on March 6, 2017.

rather than with the program. Therefore, the immediate announcement response provides a more informative comparison than the subsequent exchange rate path. The first auction at 10:00 am on March 6 produced no discernible movement.

(A) Second Announcement (Oct. 25, 2017)



(B) Third Announcement (Dec. 26, 2017)

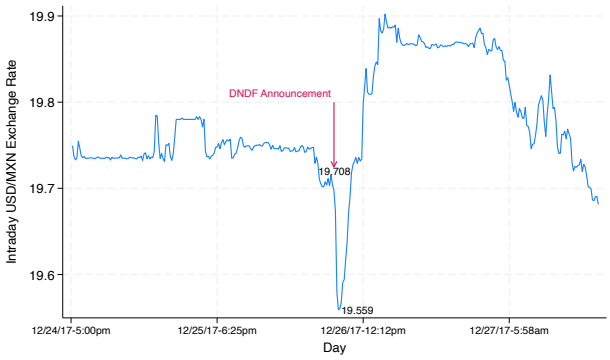


FIGURE 5. Intraday USD/MXN: Subsequent Announcements

Note: The second announcement was at 9:00 am on October 25, 2017. The third at 7:45 am on December 26, 2017.

The subsequent announcements show smaller immediate appreciations of about 20 and 13 cents, respectively (Figure 5). A regression using intraday observations estimates an appreciation of roughly 33 cents at the first announcement and no statistically significant effect at the auctions. We report the regression and additional event study figures in Appendix B. Together with the volatility evidence, these results indicate that prices responded when future insurance provision became known. The subsequent auctions added little measurable news. This is consistent with expectations of future hedging opportunities and balance sheet

protection being incorporated into current prices, along with a change in beliefs about the likelihood of a self-fulfilling depreciation.

2.5 Risk-Neutral Probability of a Large Depreciation

The decline in implied volatility does not by itself establish how the risk of a large depreciation has changed. Since DNDFs protect intermediaries in precisely those adverse outcomes, the tail of the distribution is particularly relevant. To examine it directly, we recover the right tail probability $\mathbb{Q}(e_{t+h} > \bar{e})$ from the option smile. For each date and maturity, we combine at-the-money volatility with the 25-delta risk reversal and the 25-delta butterfly, which summarize the smile's asymmetry and curvature. We fit the smile following Malz (1997) and apply Breeden and Litzenberger (1978) to recover the implied distribution. Our main measure is the probability that the peso depreciates by at least five percent beyond the forward over the life of the option.[3]

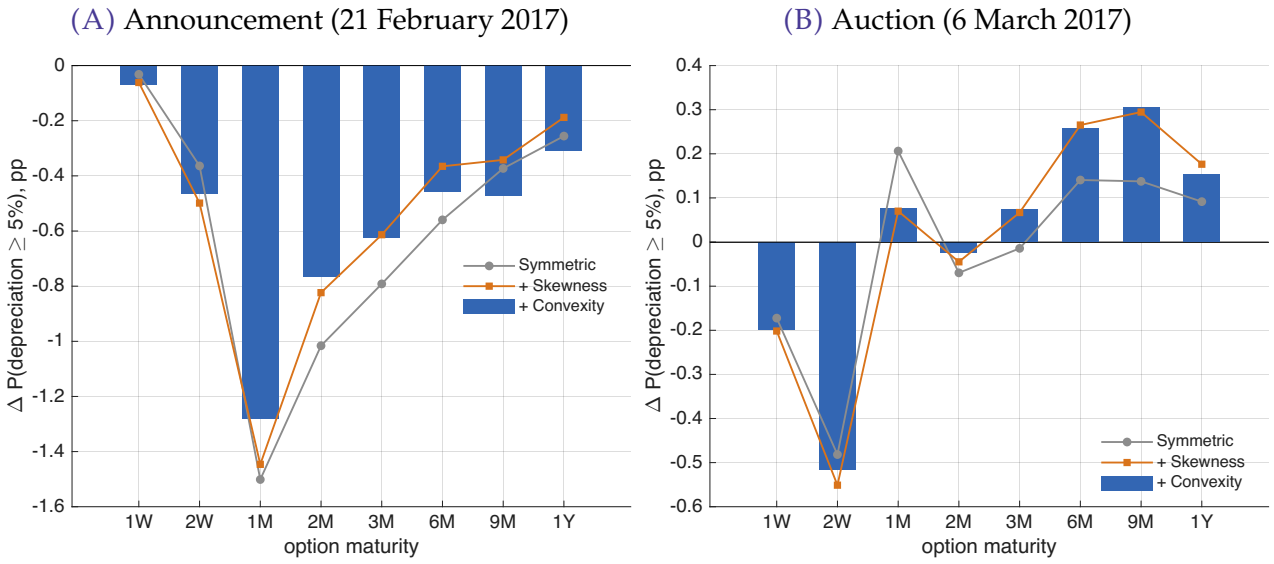


FIGURE 6. The Announcement, the Auction, and the Probability of a Large Depreciation

Note: Change in the option implied probability that the peso depreciates by at least five percent beyond the forward, in percentage points, by option maturity. "Symmetric" uses the at-the-money volatility only. The curves labeled "+ skewness" and "+ convexity" successively add the 25-delta risk reversal and butterfly, capturing the asymmetry and curvature of the volatility smile. The butterfly is not quoted at three months and is interpolated from the two- and six-month tenors. Own elaboration with data from Bloomberg.

Figure 6 shows the change in this risk-neutral depreciation probability across the maturity structure at the first announcement and its associated auction. To clarify that the finding does not rely on a symmetric benchmark, each panel plots three nested measures that successively enrich the risk-neutral distribution. These are a symmetric lognormal that uses the at-the-money volatility alone, a measure that incorporates the smile asymmetry captured by the

[3]The threshold is measured relative to the forward to account for the carry already priced at each horizon. The construction, threshold sensitivity, and numerical density checks are in Appendix B. Risk-neutral probabilities incorporate both physical probabilities and risk prices. The risk reversal and butterfly regressions below examine changes in smile shape but do not, by themselves, separate these two components.

risk reversal, and a measure that also incorporates the curvature captured by the butterfly. The announcement lowers the probability of a large depreciation at every horizon. The effect is hump-shaped in maturity, reaching approximately 1.28 percentage points at one month in the full smile measure. The three measures share the same sign and broad maturity pattern, although their magnitudes differ. The decline therefore survives the inclusion of the smile's asymmetry and curvature. The auction produces no comparable movement, and at the tenors where the announcement response is largest, the auction-day change is small.

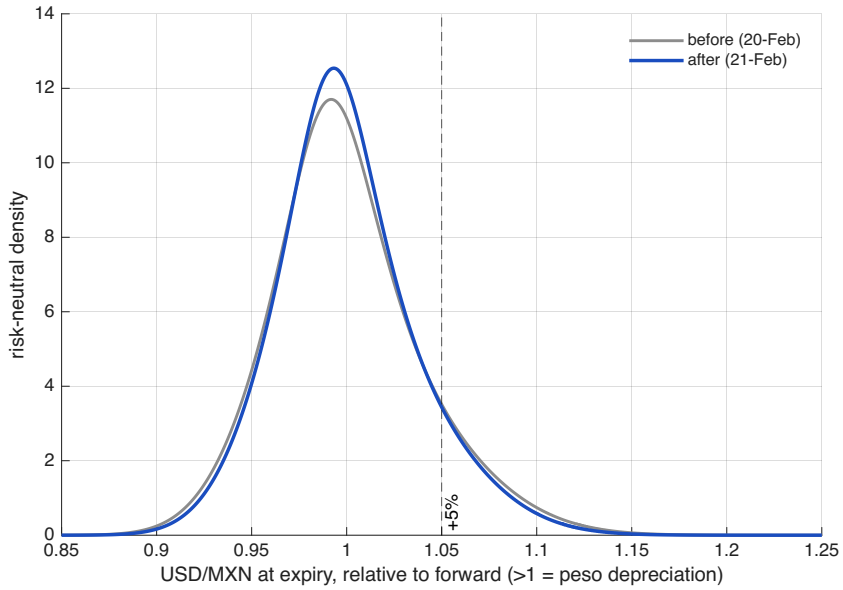


FIGURE 7. Risk-Neutral Density of the Peso Around the Announcement

Note: One-month risk-neutral density of USD/MXN at expiry, relative to the forward, on the day before and the day after the announcement. Values above one correspond to peso depreciation. Own elaboration with data from Bloomberg.

Figure 7 shows the corresponding change in the density. After the announcement, the one-month risk-neutral density concentrates around the forward, with visibly less mass in the right tail, the region of peso depreciation beyond the five-percent threshold.

The smile regressions suggest that the overall decline in volatility is the main source of the lower tail probability. When we regress the 25-delta risk reversal and butterfly on announcement and auction indicators, controlling for the same global factors as in (2), the risk reversal falls weakly at short horizons while the butterfly does not decline (Appendix B.6). These findings are consistent with a broad compression of exchange rate risk rather than a decline confined to the relative price of options that pay off after a large depreciation. The option data are daily, so the tail changes should not be interpreted as an intraday experiment holding all other news fixed. They nevertheless complement the immediate spot response by showing that the announcement was accompanied by a lower market valuation of future depreciation risk.

2.6 A Synthetic Control for Volatility

The announcement regressions exploit event timing. As a complementary design with an explicit comparison group, we apply the synthetic control method (Abadie and Gardeazabal (2003)), following Chamon et al. (2017), to the option implied volatility of the peso around the first announcement.[4] We construct a synthetic USD/MXN implied volatility counterfactual for each maturity from 1 week to 1 year, matching pre-treatment dynamics on the risk reversal measure, bond and equity flows, and lagged volatility, and filtering with an HP filter ($\lambda =$ 14,400) following Abadie (2021). Figure 8 reports the estimated treatment effect by maturity.

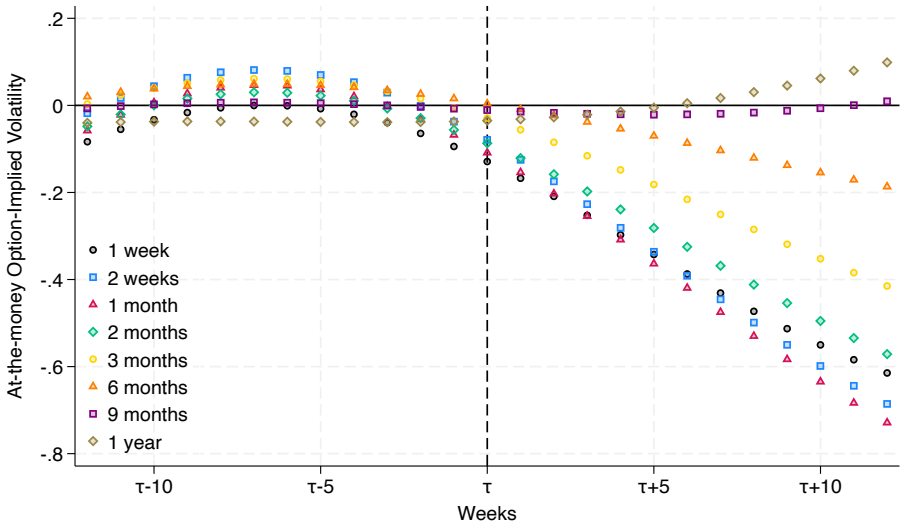


FIGURE 8. Effect on ATM Implied Volatilities, by Maturity

Note: Markers are the estimated treatment effect (observed minus synthetic implied volatility) by maturity h. t is the week of the announcement. For most horizons the countries with strictly positive weights are Brazil, Malaysia, and Turkey.

After the announcement, implied volatility falls relative to the synthetic counterfactual. Consistent with the linear model, the effect is larger for shorter maturities. The pre-treatment fit is good since the average pre-intervention gap is near zero at each h, and the placebo distribution in Appendix B places Mexico among the largest contractions at short maturities. For the level of the peso, the analogous synthetic control in Appendix B yields an appreciation of about 15 cents three months out. We treat this as complementary evidence because the level is secondary to our argument and persistence in the level is difficult to attribute over a twelve-week window.

[4]Data limitations preclude a high-frequency donor pool, so the synthetic control is estimated at a weekly frequency around the first announcement only. The donor pool comprises 19 emerging and comparable economies chosen based on data availability and fundamentals. The methodology, level synthetic control, and placebo tests are reported in Appendix B.

2.7 Scale of the Announced Program

The evidence so far places the market response at the announcement. To understand what participants could anticipate on that date, we consider the scale of the promised insurance and the terms on which it was later supplied. The first announcement established a facility of up to USD 20 billion in non-deliverable forwards. The subsequent announcements increased the amount to be auctioned within this limit. One reason such a commitment can affect expectations is that it promises to relieve a shortage of hedging in the private market. This is the channel that Gonzalez et al. (2026) identify for Brazil's earlier and closely related program, in which intermediaries with more foreign debt cut lending as private hedging became scarce and costly, while the central bank's supply of forwards relaxed that constraint. We cannot trace that channel here since we do not have access to matched credit, external funding, and employment registers of the kind their exercise requires. We observe the primary market for insurance and the allocation of forwards across intermediaries at the auctions, but we do not know how those intermediaries subsequently use them.

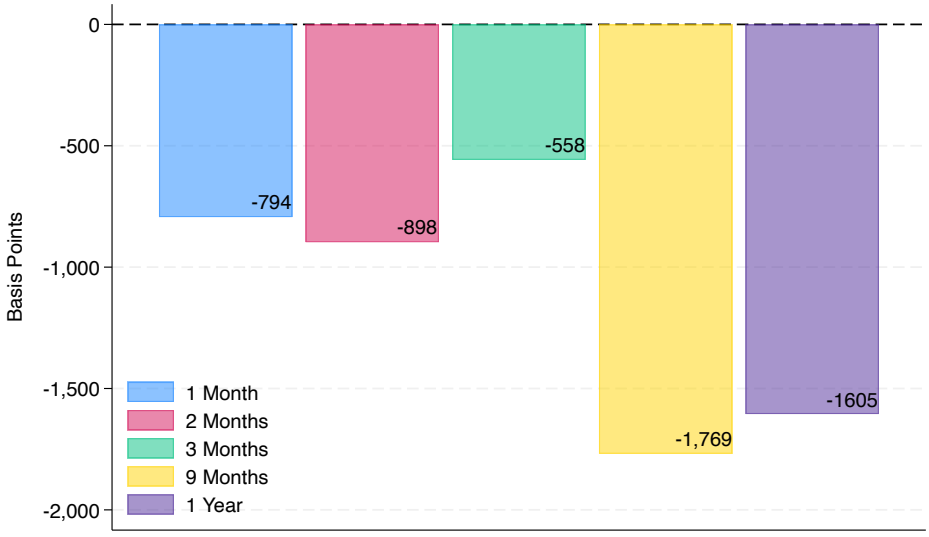


FIGURE 9. Comparison of Forward Points: Auction vs. Market

Note: Bars display, for each maturity, the average difference between the auction forward rate and the market forward rate.

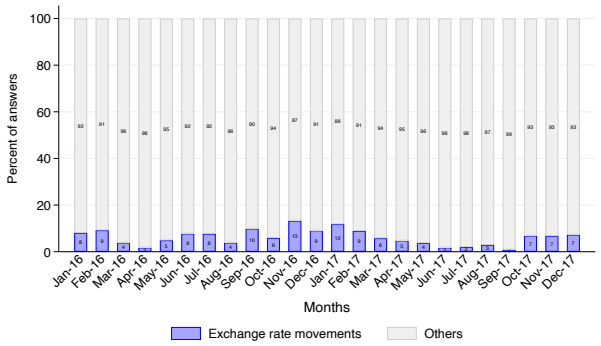
The announcement and auction contrast locates the market response at the commitment to future provision. Participating institutions could anticipate the availability of central bank insurance and adjust their assessment of future financing conditions before bidding. A public commitment can also affect beliefs about whether other participants will continue to lend and borrow in an adverse state. Both effects are consistent with the timing we document. Our data do not separately identify their contributions, but they show that the response did not wait for contracts to be issued. This is the sense in which the evidence supports an expectations channel.

Consistent with a floating regime, the program did not announce a target for the peso. Figure 9 compares auction and contemporaneous market forward points by maturity across the nine 2017 auctions. Auction pricing was favorable relative to the market on average (i.e., forward rates from the auction were, on average, below market forward rates). These outcomes can matter for intermediaries' expected hedging costs, even though a particular forward price was not the announced policy objective. We therefore interpret the commitment's scale and expected terms jointly as features that can change beliefs about future insurance provision. The model makes this connection explicit by allowing the promised forward rate to affect lending conditions and subsequent collateral values.

2.8 Expectations of the Private Sector

Option prices value risk as well as reflect beliefs about future outcomes. To complement that evidence with reported expectations, we use the Bank of Mexico's monthly survey of private sector specialists. The survey records expectations about the business climate, the main factors limiting growth, and the expected level of the exchange rate from month t to $t + 12$. The most telling series is the share of specialists naming exchange rate movements among

(A) ER Movements as a Main Limit to Growth



(B) Survey Responses on the Business Climate

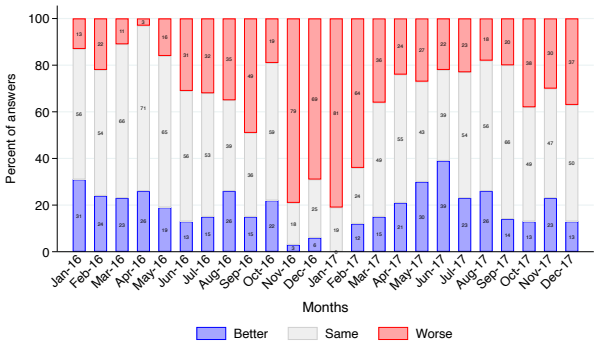


FIGURE 10. Survey Evidence from Banco de México

Note: Own elaboration with data from Banco de México. Panel (a) shows the share of specialists citing each factor as a main limitation to growth. "Exchange rate movements" bundles "FX uncertainty" and "real exchange rate." Panel (b) shows the shares of responses on whether the business climate will be better, the same, or worse than the previous six months.

the main factors limiting growth (Figure 10A). This share was elevated at the end of 2016 and the start of 2017, then declined after February 2017.[5] We cannot attribute these low-frequency movements causally to the program, since other economic and political developments also affected the outlook, but the timing of the reversal, coinciding with the announcement, is notable. The exchange rate forecasts show a similar change (Figure 11). In January 2017, specialists expected a persistently weaker peso over the following twelve months. The

[5]Over the same window, the share reporting a worse business climate, which had risen sharply after the election from 22% before the election to 81% when Trump took office, also began to reverse (Figure 10B).

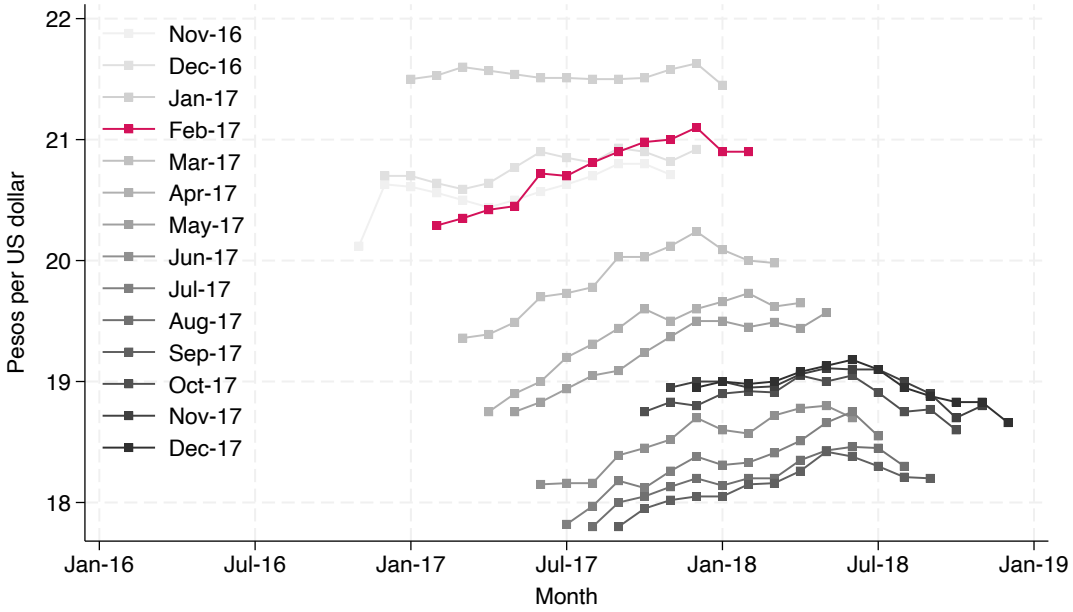


FIGURE 11. Expected USD/MXN Exchange Rate, Month t to $t + 12$

Note: Own elaboration with data from Banco de México. For each month t (one curve per month), the median forecast of the exchange rate at t through $t + 12$.

expected path shifted down from February onward and rose again around October, near the subsequent announcement. Together with the financial market evidence, these observations are consistent with the commitment to insurance changing expectations of future exchange rates and financial conditions. The model developed next studies how anticipated insurance payments affect borrowing and collateral, and how these effects alter the set and severity of self-fulfilling depreciations.

3 Model

The empirical evidence places the exchange rate response at the announcement of future insurance provision. We now develop a model in which that commitment changes current lending and the possibility of a self-fulfilling crisis. Financial intermediaries bear currency risk because they fund domestic currency loans with dollar debt. Households' borrowing capacity depends on the value of their income. Hence, a contraction in spending can reduce collateral and validate pessimistic expectations. Downward nominal wage rigidity turns the decline in demand for nontradables into unemployment. The model brings these forces together to study how anticipated insurance payments affect both credit supply and the collateral available to support it.

3.1 Environment

3.1.1 Private Sector

Households The economy consists of homogeneous households of unit measure. Households maximize lifetime utility subject to budget and borrowing constraints specified as

$$\max_{\{c_t, M_{t+1}, d_{t+1}\}_{t\geq 0}} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t \left(u(c_t) + v\left(\frac{M_{t+1}}{p_t}\right)\right)\right] \tag{3}$$

$$\text{s.t. } p_t^T c_t^T + p_t^N c_t^N + \tilde{R}_{t-1}\frac{e_{t-1}d_t}{R_{t-1}} + M_{t+1}$$

$$= p_t^T y_t^T + w_t h_t + \frac{e_t d_{t+1}}{R_t} + M_t + \Pi_t - T_t, \tag{4}$$

$$c_t = \left(\phi (c_t^T)^{\frac{\gamma-1}{\gamma}} + (1-\phi)(c_t^N)^{\frac{\gamma-1}{\gamma}}\right)^{\frac{\gamma}{\gamma-1}}, \tag{5}$$

$$\frac{e_t d_{t+1}}{R_t} \leq \kappa(p_t^T y_t^T + w_t h_t) \tag{6}$$

where p_t^T and p_t^N are the prices of tradables and nontradables, respectively. The household income is composed of the endowment of tradables $p_t^T y_t^T$ and the labor income $w_t h_t$ from the production of nontradables. The tradables endowment is stochastic in the baseline model. Section 4 considers a deterministic version with a constant endowment. We assume that the law of one price holds, with the tradable good being the numeraire in the world economy. The price of tradables is equivalent to the nominal exchange rate, i.e., $p_t^T = e_t$.

Households borrow $e_t d_{t+1}/R_t$ units of domestic currency from financial intermediaries in period t at the gross interest rate $\tilde{R}_t$. Intermediaries fund these loans by borrowing d_{t+1}/R_t dollars abroad at the gross world interest rate R_t, with d_{t+1} dollars due next period. Households also hold nominal money balances M_{t+1} because real money balances enter utility. The lump-sum tax T_t finances the central bank, as described below, and Π_t represents intermediary profit distributed to households.

The intratemporal optimal choice between tradable and nontradable consumption satisfies

$$\frac{p_t^N}{e_t} = \frac{1-\phi}{\phi}\left(\frac{c_t^N}{c_t^T}\right)^{-\frac{1}{\gamma}}, \tag{7}$$

and the consumption price index p_t is obtained as

$$\left(\phi^\gamma e_t^{1-\gamma} + (1-\phi)^\gamma \left(p_t^N\right)^{1-\gamma}\right)^{\frac{1}{1-\gamma}} = p_t. \tag{8}$$

The money demand is determined by the first-order condition with respect to M_{t+1},

$$\frac{1}{p_t} v' \left(\frac{M_{t+1}}{p_t} \right) = \frac{u_T(t)}{e_t} - \beta \mathbb{E}_t \left[\frac{u_T(t+1)}{e_{t+1}} \right], \tag{9}$$

where $u_T(\cdot)$ denotes the partial derivative of $u(\cdot)$ with respect to tradable consumption.

Households' loan proceeds cannot exceed a fraction κ of their endowment and labor income before taxes and distributions of intermediary profits. Borrowing capacity therefore falls when depreciation lowers the dollar value of nontradable income, creating a link between the exchange rate, collateral, and spending. We consider the borrowing constraint to be similar to that in the literature, including Bianchi (2011). The first-order condition with respect to d_{t+1} yields the following Euler equation:

$$(1 - \mu_t) \frac{u_T(t)}{e_t} = \beta \tilde{R}_t \mathbb{E}_t \left[\frac{u_T(t+1)}{e_{t+1}} \right], \tag{10}$$

where $\mu_t \geq 0$ is the normalized Lagrange multiplier on the borrowing constraint.[6] The complementary slackness condition associated with the borrowing constraint is given by

$$\mu_t \left(\kappa \left(e_t y_t^T + w_t h_t \right) - \frac{e_t d_{t+1}}{R_t} \right) = 0, \quad \mu_t \geq 0. \tag{11}$$

Nontradables Production Nontradable goods are produced by homogeneous firms with linear production technology $y_t^N = h_t$, and households inelastically supply labor up to $\overline{h}$ units.[7] The equilibrium hours worked are $h_t \leq \bar{h}$ due to downward wage rigidity such that $w_t \geq w_{t-1}$. There is unemployment such that $h_t < \overline{h}$ only when the wage is restricted to its lower bound w_{t-1}. Hence, we have the following:

$$(w_t - w_{t-1})(h_t - \overline{h}) = 0, \tag{12}$$

as a complementary slackness condition that holds in equilibrium. The linear production function implies that the price of nontradables satisfies

$$p_t^N = w_t, \tag{13}$$

which implies that the price of nontradables is subject to downward rigidity as well.

Financial Intermediaries A unit measure of identical, risk-averse financial intermediaries funds domestic lending entirely through external borrowing. Each intermediary borrows d_{t+1}/R_t dollars and lends the domestic currency proceeds to households at the gross rate $\tilde{R}_t$. Its loan repayment is fixed in domestic currency, while its external debt must be repaid in

[6] We put λ_t as the multiplier on the period budget constraint and $\lambda_t \mu_t$ as the multiplier on the borrowing constraint. Solving for the Lagrangian yields $\lambda_t = u_T(t)/e_t$ and equation (10).

[7] We abstract from labor disutility for simplicity.

dollars. The intermediary therefore bears exchange rate risk and maximizes the following mean-variance objective

$$\max_{d_{t+1}} W_t = \mathbb{E}_t[\Pi_{t+1}] - \frac{\omega}{2}\text{Var}_t[\Pi_{t+1}], \tag{14}$$

$$\text{s.t. } \Pi_{t+1} = \tilde{R}_t e_t \frac{d_{t+1}}{R_t} - e_{t+1} d_{t+1}, \tag{15}$$

which yields the optimal condition with respect to d_{t+1} as

$$d_{t+1} = \frac{1}{\omega \text{Var}_t\left[e_{t+1}\right]} \left(\frac{\tilde{R}_t}{R_t} e_t - \mathbb{E}_t e_{t+1} \right), \tag{16}$$

so positive lending requires compensation for exchange rate risk whenever the conditional variance is positive. The resulting interest differential departs from uncovered interest parity.

When the central bank offers a forward contract to the financial intermediaries, the financial intermediaries can choose the fraction $\theta_t \in [0, 1]$ of their debt to be covered by the forward contract at the forward rate f_t. Its objective changes to

$$\max_{d_{t+1}, \theta_t \in [0,1]} W_t = \mathbb{E}_t[\Pi_{t+1}] - \frac{\omega}{2}\text{Var}_t[\Pi_{t+1}], \tag{17}$$

$$\text{s.t. } \Pi_{t+1} = \tilde{R}_t e_t \frac{d_{t+1}}{R_t} \left((1-\theta_t) + \theta_t \frac{e_{t+1}}{f_t} \right) - e_{t+1} d_{t+1}, \tag{18}$$

The intermediary chooses lending and insurance jointly. For positive borrowing, the optimal lending condition is

$$\begin{aligned} 0 = \frac{\tilde{R}_t}{R_t} e_t (1-\theta_t) + \left(\frac{\tilde{R}_t e_t \theta_t}{R_t f_t} - 1 \right) \mathbb{E}_t[e_{t+1}] \\ - \omega d_{t+1} \left(\frac{\tilde{R}_t e_t \theta_t}{R_t f_t} - 1 \right)^2 \text{Var}_t(e_{t+1}), \end{aligned} \tag{19}$$

The coverage condition is

$$\mathbb{E}_t[e_{t+1}] - f_t - \omega d_{t+1} \left(\frac{\tilde{R}_t e_t \theta_t}{R_t f_t} - 1 \right) \text{Var}_t(e_{t+1}) \begin{cases} \leq 0, & \theta_t = 0, \\ = 0, & 0 < \theta_t < 1, \\ \geq 0, & \theta_t = 1. \end{cases} \tag{20}$$

At an interior coverage choice, the two conditions imply covered interest parity,

$$f_t = \frac{\tilde{R}_t}{R_t} e_t. \tag{21}$$

Covered interest parity also holds at full coverage with finite positive lending. In that case, the intermediary has no exchange rate exposure and earns zero profit, and $f_t \leq \mathbb{E}_t[e_{t+1}]$. At zero

coverage, $(\tilde{R}_t/R_t)e_t = \mathbb{E}_t[e_{t+1}] + \omega d_{t+1}\,\mathrm{Var}_t(e_{t+1})$ and $f_t \geq (\tilde{R}_t/R_t)e_t$. Thus the forward rate affects both the exchange rate exposure the intermediary retains and the repayment it requires on domestic lending.

3.1.2 Central Bank

The central bank has two main policy instruments. First, it sets the money supply M_t. In equilibrium, the marginal utility terms satisfy (9) given a level of M_t.

Second, the central bank sets the forward rate f_t to insure financial intermediaries against currency depreciation. At the beginning of each period, it settles the DNDFs issued in the previous period using its net foreign assets a_t. The central bank borrows and lends at the gross world interest rate R_t.[8] We also impose that the central bank must keep its discounted net foreign asset position above $\underline{a}$ after settling the contracts.[9] Hence, the central bank's net foreign assets evolve according to the following rule:

$$\frac{a_{t+1}}{R_t} = \max\left\{a_t - \left(\frac{1}{f_{t-1}} - \frac{1}{e_t}\right)\theta_{t-1}\tilde{R}_{t-1}e_{t-1}\frac{d_t}{R_{t-1}}, \underline{a}\right\}. \tag{22}$$

To focus on the role of insurance provision, we assume that the central bank pays out all the revenues from an increase in the money supply and taxes the private agents only to replenish the assets whenever they fall below $\underline{a}$. Hence, the lump-sum tax T_t is determined to satisfy the central bank's budget constraint in domestic currency units as

$$T_t = -(M_{t+1} - M_t) + e_t\left(\frac{a_{t+1}}{R_t} - a_t + \left(\frac{1}{f_{t-1}} - \frac{1}{e_t}\right)\tilde{R}_{t-1}e_{t-1}\theta_{t-1}\frac{d_t}{R_{t-1}}\right). \tag{23}$$

3.1.3 Market Clearing

The market clearing condition for nontradables is given as $c_t^N = y_t^N$. Plugging this and (23) into the household sequential budget constraint, we obtain the following resource constraint for tradable goods:

$$c_t^T + (d_t - a_t) = y_t^T + \frac{d_{t+1} - a_{t+1}}{R_t}. \tag{24}$$

Nontradables market clearing implies $h_t = c_t^N$.

[8] While we denote a_t as the central bank's external asset following the convention of the literature, it can also be conceptualized as the central bank's equity, which is provided by fiscal law. Indeed, the Bank of Mexico paid private institutions out of its equity when implementing the DNDF program.

[9] An alternative way to ensure that the central bank does not use the forward contracts to inject an infinite amount of resources into the private sector would be to specify a cap on the number of dollars that the central bank can sell through the forwards. This would introduce a capacity constraint in the financial intermediaries' problem.

3.1.4 Exogenous Processes

We introduce both fundamental and nonfundamental risks to this economy. The fundamental risks stem from the risks in the tradable endowment y_t^T and the world interest rate R_t, and we assume that these two variables follow stationary AR(1) processes, respectively. The processes could be written as

$$\log y_t^T = \rho_y \log y_{t-1}^T + \epsilon_t^y, \quad \epsilon_t^y \sim N(0, \sigma_y^2), \tag{25}$$

$$\log \frac{R_t}{R} = \rho_R \log \frac{R_{t-1}}{R} + \epsilon_t^R, \quad \epsilon_t^R \sim N(0, \sigma_R^2). \tag{26}$$

We consider the coordination failure of households' beliefs about future exchange rates to be the source of nonfundamental risk that can lead to unexpected fluctuations in the exchange rate. Previous works by Schmitt-Grohé and Uribe (2021) and Bianchi and Coulibaly (2026) find that there are sunspot equilibria with a binding borrowing constraint when the debt d_t at the beginning of the period exceeds a certain level, even when there is no fundamental risk. In line with these studies, we introduce an exogenous binary sunspot ι_t with $\Pr(\iota_t = 1) = \pi$. The sunspot selects among equilibria without changing fundamentals. The pessimistic realization $\iota_t = 1$ selects an equilibrium with a binding borrowing constraint when one exists.

3.1.5 Competitive Equilibrium

We define the competitive equilibrium of this economy as follows.

Definition 1 (Equilibrium under DNDF Policy). *Given initial conditions* $\{f_{-1}, \theta_{-1}, \tilde{R}_{-1}, R_{-1}, e_{-1}, w_{-1}, M_0, d_0, a_0\}$, *exogenous processes* $\{y_t^T, R_t, \iota_t\}_{t=0}^{\infty}$, *and a sequence of* $\{f_t, M_t\}_{t=0}^{\infty}$, *the competitive equilibrium is defined as a sequence of allocations* $\{c_t^T, c_t^N, c_t, h_t, d_{t+1}, \Pi_t, \theta_t, \mu_t\}_{t=0}^{\infty}$, *prices* $\{e_t, p_t^N, p_t, w_t, \tilde{R}_t\}_{t=0}^{\infty}$, *and* $\{a_{t+1}, T_t\}_{t=0}^{\infty}$ *such that*

1. *Given initial debt* d_0, *tradable endowment* y^T, *prices, and policy* $\{f_t, T_t, a_{t+1}\}_{t=0}^{\infty}$, *households maximize their lifetime utility, and firms maximize profit each period. That is, equations (4)–(6) and (7)–(13) hold.*

2. *Given the forward rate* f_t *and prices, financial intermediaries maximize their mean-variance objective with profit defined by (18). That is, equations (19) and (20) hold.*

3. *Given the initial asset* a_0, *the forward rates* $\{f_t\}_{t=0}^{\infty}$, *and debt* $\{d_t\}_{t=0}^{\infty}$, *the central bank asset* a_{t+1} *evolves according to (22) and the lump-sum tax* T_t *satisfies (23) each period.*

4. *Markets clear and (24) holds.*

3.2 Discussion of Assumptions

We discuss the relevance of some simplifying assumptions to our analysis of the effects of the DNDF policy.

Currency Choice of Central Bank Assets. We abstract from constructing the central bank's problem of choosing the optimal currency portfolio. While we impose that the central bank's net foreign assets are denominated in foreign currency, our discussion so far does not rely on the currency denomination of these assets. What matters is whether private agents believe that the central bank has enough resources to pay them the DNDF settlements when the exchange rate actually depreciates today. A sufficiently low borrowing floor $\underline{a}$ allows the central bank to finance settlements without an immediate offsetting tax. In reality, the DNDF settlement does not directly affect the central bank's foreign reserves. This reinforces market participants' belief that the central bank can cover the DNDF settlements if necessary.

Private FX Forward Market. We abstract from a separate private forward market to isolate the effects of central bank insurance on intermediaries' exchange rate exposure. This does not require that participating institutions have access to private hedges. In Mexico, the public commitment could change the expected availability and cost of insurance even where private contracts are already traded. The model represents the effect of that provision on lending conditions and aggregate collateral rather than the allocation of hedging across private counterparties. We now proceed to discuss how the central bank's choice of policy affects the equilibrium, focusing on the role of DNDF policy.

4 Equilibrium Analysis

We first hold fundamentals constant to show how a crisis can arise from expectations alone. If households expect others to reduce borrowing, the resulting fall in consumption weakens nontradable income and collateral, making the anticipated deleveraging consistent with equilibrium. DNDF settlements can interrupt this feedback by supporting private resources when the currency depreciates. We study how this protection changes the set and severity of crisis equilibria and then compare it with a tax on borrowing. This analysis provides the economic basis for equilibrium selection in the stochastic model.

4.1 Steady State Equilibrium

For expositional purposes, we focus on a special case where $\beta R = 1$, $u(c) = \log c$, and $v(m) = \chi \log m$ with $m \equiv \frac{M}{p}$. The central bank is endowed with zero initial assets and a sufficiently low $\underline{a} < 0$.[10] We define a steady state equilibrium where all allocations are

[10] In this case, we interpret $\underline{a}$ as the maximum deficit that the central bank can run with.

constant and there is no unemployment over time. The money supply is kept constant at a level that satisfies the money demand equation, and there is no inflation. Under constant allocations with $a_0 = 0$, the central bank maintains its assets by not transferring resources to private agents and by setting the forward rate f equal to the exchange rate e.

In a deterministic environment in the absence of uncertainty, financial intermediaries would borrow an infinite amount of debt as long as they earn positive profits. Hence, we consider the case where the intermediaries earn zero profit $\Pi = 0$. Since the intermediaries' problem becomes degenerate, the external debt is directly chosen by the households to satisfy (10). The choice of θ_t also becomes indeterminate, so we impose that a constant fraction of $\theta \in (0, 1]$ is covered by the forward contract when $f = e$. Then, the interest rate parity condition implies $\tilde{R}_t = R$ at the steady state by

$$\tilde{R}_t e_t = R e_{t+1} \tag{27}$$

which is reduced to (21) when $\theta = 1$.

The resource constraint (24) and the market clearing condition for nontradables imply that

$$c^T = y^T - \frac{R-1}{R} D_0, \tag{28}$$

given an initial level of aggregate debt D_0. The steady state exchange rate e satisfies

$$\frac{w_{-1}}{e} = \frac{1-\phi}{\phi} \left(\frac{\bar{h}}{c^T} \right)^{-\frac{1}{\gamma}}, \tag{29}$$

given w_{-1} with downward wage rigidity and $y^N = \bar{h}$ under full employment. Plugging this into the borrowing constraint (6), the steady state borrowing limit is given by:

$$\kappa R \left(y^T + \frac{p^N}{e} y^N \right) = \kappa R \left(y^T + \left(\frac{1-\phi}{\phi} \right)^{\gamma} \left(\frac{w_{-1}}{e} \right)^{1-\gamma} \left(y^T - \frac{R-1}{R} D_0 \right) \right) \equiv \bar{d}^{ss}(D_0), \tag{30}$$

and $\bar{d}^{ss}(D_0)$ is a decreasing function of D_0 as in Bianchi and Coulibaly (2026). Hence, there exists a fixed point such that $\hat{D} = \bar{d}^{ss}(\hat{D})$, and we focus on the case where the initial debt is $D_0 < \hat{D}$, so that there exists a steady state equilibrium in which allocations are constant. The borrowing constraint does not bind in that equilibrium because the household Euler equation also implies $\mu = 0$ when $f = e$. In sum, the steady state allocation we consider here is identical to the steady state without DNDF policy and the central bank's external assets considered by Bianchi and Coulibaly (2026).

For further analysis, we assume that the following assumption holds in a steady state.

Assumption 1. *Given initial debt D_0, initial wage w_{-1}, and interest rate R, the elasticity of substitution γ satisfies the following condition:*

$$\left(\frac{1-\gamma}{\gamma}\right) \times (R-1) < 1. \tag{31}$$

Assumption 1 imposes a lower bound for γ, so the elasticity of substitution between tradables and nontradables is sufficiently high. We also impose $R < 2$ so that the international interest rate does not exceed 100%. Note that empirically relevant values of γ around 0.5, as surveyed by Akinci (2011), satisfy Assumption 1. We consider values of $\gamma \in (0,1)$ that satisfy this assumption in the analysis henceforth.

4.2 Multiple Equilibria under DNDF Policy

The economy without the DNDF policy features multiple equilibria at time t, as proved by Schmitt-Grohé and Uribe (2021) and Bianchi and Coulibaly (2026) when the initial debt D_0 exceeds a certain threshold. We now analyze how the DNDF policy imposed in the steady state affects these multiple equilibria.

Consider a deterministic case in which there is no DNDF policy, and the economy has been at the steady state with initial aggregate debt D_0 until period t, reaching a different steady state in period $t+1$ with aggregate debt D_{t+1} chosen at period t. We assume that the central bank prevents nominal wages from rising to keep the inflation rate as low as possible, as it takes into account households' utility associated with real money balances. Bianchi and Coulibaly (2026) show that a steady state equilibrium and at least one self-fulfilling crisis equilibrium, in which borrowing is constrained at a lower level than $D_t = D_0$, can exist when D_t is above a threshold level. These equilibria are marked as points F, F', and G in Figure 12. We begin with a brief explanation of the multiplicity of equilibria in our model.

The horizontal axis of Figure 12 is the aggregate debt D_{t+1} and the vertical axis is each individual's debt choice d_{t+1}. The downward sloping line is the steady state debt limit $\bar{d}^{ss}(D_{t+1})$ defined over potential values of D_{t+1}. This is the debt limit that would have prevailed if all agents entered and left the period with debt D_{t+1}. The blue upward-sloping curve is each individual's borrowing limit in time-t equilibrium,

$$\bar{d}(D_{t+1}; D_t) \equiv \kappa R \left(y^T + \left(\frac{1-\phi}{\phi}\right)^{\gamma} \left(\frac{w_{t-1}}{e_t}\right)^{1-\gamma} \left(y^T + \frac{D_{t+1}}{R} - D_t \right) \right), \tag{32}$$

as a function of aggregate debt D_{t+1} chosen at time t given initial debt D_t. This is the debt limit up to which each household can borrow when it expects all other households to borrow D_{t+1}. $\bar{d}(D_{t+1}; D_t)$ is an increasing function of D_{t+1} because higher debt issuance

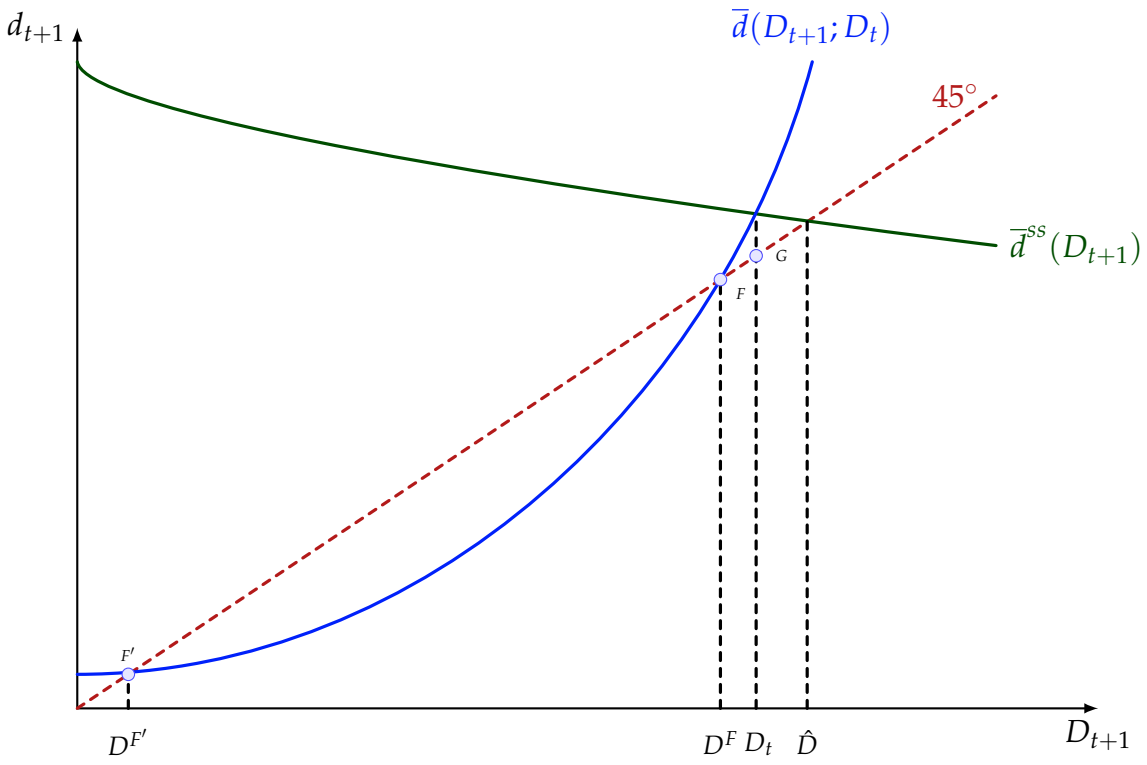


FIGURE 12. Multiple Equilibria without DNDF Policy

Note: The upward-sloping curve plots the equilibrium borrowing limit given initial debt D_t. The downward-sloping curve plots the steady state borrowing limit, and the red dashed line is the 45-degree line.

today increases consumption and raises the income from nontradable production. The figure illustrates the convex case.

Since private agents are homogeneous, we consider symmetric equilibria where everyone borrows $d_{t+1} = D_{t+1}$ and all possible equilibria are located on the 45-degree line. One possible equilibrium is the steady state equilibrium where $d_{t+1} = D_{t+1} = D_t$. This corresponds to point G in Figure 12 and the steady state debt limit $\overline{d}^{ss}(D_{t+1})$ intersects the equilibrium debt limit $\overline{d}(D_{t+1}; D_t)$ at $D_{t+1} = D_t$. This is the case when each person expects all others to borrow D_t as well in time t and correspondingly borrows D_t. However, there are other equilibria when all the private agents become pessimistic and believe that the exchange rate depreciates today. This is the case when the private agents collectively deleverage at time t, inducing a self-fulfilling crisis and making the borrowing constraint bind, as shown by Bianchi and Coulibaly (2026).[11] These are points F or F' where the blue upward-sloping line meets the 45-degree line. The exchange rate depreciates, and lower consumption induces unemployment in the crisis equilibria F and F'. The household Euler equation implies that the borrowing constraint binds with $\mu_t > 0$ at these deleveraging equilibria.

We now analyze how the DNDF policy affects the multiple equilibria in Figure 13. Consider

[11] Such an equilibrium exists when the slope of $\overline{d}(D_{t+1}; D_t)$ at $D_{t+1} = D_t$ is greater than 1 and D_t is larger than a threshold level. Technically, this yields the result that the debt limit $\overline{d}(D_{t+1}; D_t)$ decreases faster than D_{t+1} and intersects the 45-degree line as D_{t+1} decreases.

that the economy has been at the steady state with initial debt D_0 and the central bank's zero asset position until period $t-1$. To make the equilibrium under the DNDF policy comparable to the laissez faire case, we consider the deterministic environment in which the crisis can happen only at time t and the economy reaches the new steady state in time $t+1$ and afterwards. For this comparison, the forward rates chosen in period t and afterwards satisfy $f_j = e_{j+1}, \forall j \geq t$, thereby ensuring that the fraction of debt being covered by the forward contract is kept constant at θ without reaching its boundaries. In this sense, we impose a forward rate rule for f_t that depends on the aggregate debt D_{t+1} chosen at time t such that

$$f_t(D_{t+1}) = \frac{\phi}{1-\phi}\left(\frac{\bar{h}}{y^T - (1-\beta)D_{t+1}}\right)^{\frac{1}{\gamma}} w_{t-1}. \tag{33}$$

This rule of $f_t(D_{t+1})$ corresponds to the steady state level of the exchange rate when the initial debt is given as D_{t+1} starting from time $t+1$. It is increasing in D_{t+1} as larger debt at the new steady state implies lower consumption and a higher price of tradable goods in equilibrium.[12]

With the DNDF policy specified as above, the borrowing limit that private agents face at period t becomes

$$\begin{aligned}\bar{d}(D_{t+1}; D_t) &\equiv \kappa R\left(y^T + \left(\frac{1-\phi}{\phi}\right)^{\gamma}\left(\frac{w_t}{e_t}\right)^{1-\gamma}\left(y^T + \frac{D_{t+1}-a_{t+1}}{R} - D_t + a_t\right)\right) \\ &= \kappa R\Bigg(y^T + \left(\frac{1-\phi}{\phi}\right)^{\gamma}\left(\frac{w_t}{e_t}\right)^{1-\gamma}\Bigg(y^T + \frac{D_{t+1}}{R} - D_t + \underbrace{\frac{e_t - e}{e_t}\theta D_t}_{\text{DNDF Settlement}}\Bigg)\Bigg),\end{aligned} \tag{34}$$

as the central bank has been imposing $f = e$ until period $t-1$ with $\underline{a}$ being sufficiently low such that the private agents know that the central bank can pay out the DNDF settlement. Under DNDF insurance, the curvature must be checked separately, as shown in Appendix C.3.

In a crisis equilibrium, higher aggregate borrowing supports consumption and nontradable income, raising the borrowing limit $\bar{d}(D_{t+1}; D_t)$. Appendix C.3 derives this relationship. We now show that the exchange rate depreciates in a self-fulfilling crisis with $D_{t+1} < D_t$ as in Bianchi and Coulibaly (2026).

[12] The one-period borrowing limit comparison conditions on the stated private continuation allocation and fixed nominal wage isolate the effect of the settlement on current collateral. After a nonzero settlement, this continuation need not coincide with that of the full economy once the central bank's position is closed through household taxes. Section 5 includes that fiscal adjustment explicitly in the dynamic and welfare comparisons.

Remark 1. *Starting from the initial steady state, a decline in aggregate borrowing ($D_{t+1} < D_t$) leads to exchange rate depreciation.*

Proof. See Appendix C.1. ■

One immediate result of Remark 1 is that the DNDF settlement partly offsets the decrease in c_t^T in a sunspot equilibrium. Among equilibria with a depreciation, increasing coverage raises the borrowing limit at a given aggregate debt choice. The derivative in Appendix C.3 accounts for the induced exchange rate response. Moreover, the policy restricts the space of D_{t+1} where the sunspot equilibrium can occur at time t.

Remark 2. *Crisis equilibrium requires that $D_{t+1} < D_t - \frac{e_t - e}{e_t} R\theta D_t$.*

Proof. See Appendix C.2. ■

Remark 2 illustrates why a self-fulfilling crisis under DNDF insurance requires more pessimistic expectations. The payment partly offsets the contraction in consumption, so households must expect a larger reduction in aggregate borrowing to sustain a self-fulfilling depreciation. In the crisis equilibrium, unemployment happens as in Bianchi and Coulibaly (2026).

We illustrate how the DNDF policy would affect the multiple equilibria in Figure 13. Since the central bank's transfer raises the borrowing limit in equilibria with a depreciation, we can draw $\overline{d}(D_{t+1}; D_t)$ under policy as the solid upward-sloping line in Figure 13. It intersects with the steady state debt limit $\overline{d}^{ss}(D_{t+1})$ when $D_{t+1} = D_t$ because there will be no payment without any depreciation. Self-fulfilling crises can potentially occur in two candidate points H and H'.

At the upper crisis intersection F in Figure 13, the borrowing limit is steeper than the 45-degree line. Raising the limit therefore moves this intersection leftward to H, so households must expect a larger reduction in aggregate borrowing for a crisis to arise.

The DNDF settlement boosts the debt limit across values of $D_{t+1} < D_t$ in Figure 13. At the lower crisis intersection F', the borrowing limit is flatter than the 45-degree line, so the same upward shift moves the intersection rightward to H'. Households borrow more in this worst equilibrium, reducing the severity of the crisis. Whether the self-fulfilling crisis is completely eliminated depends on the parametrization of the model.

We lastly study how the DNDF settlement under the forward rate rule (33) affects the feasibility of multiple equilibria. Bianchi and Coulibaly (2026) show that the existence of multiple equilibria depends on the level of initial debt D_t that the households begin with, and the crisis equilibrium does not exist when the initial debt D_t is below a threshold

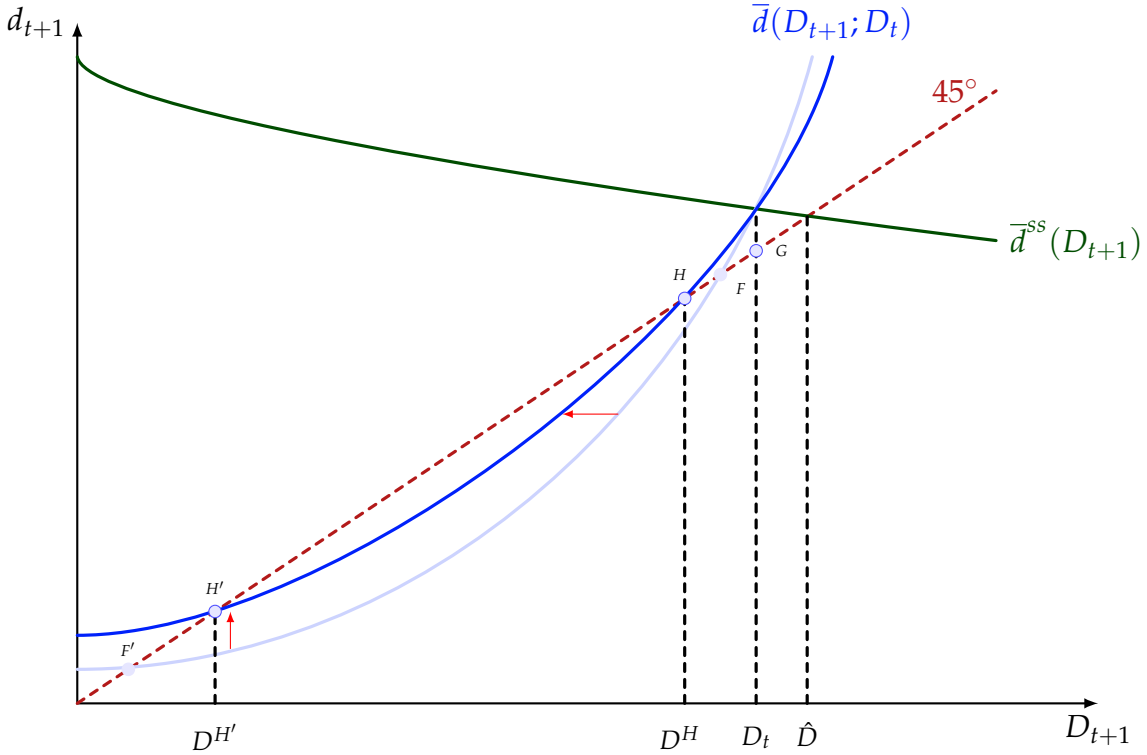


FIGURE 13. Multiple Equilibria under DNDF Policy

Note: Dark and light blue upward-sloping curves plot the equilibrium borrowing limit with and without DNDF insurance, respectively. Downward-sloping curve $\overline{d}^{ss}(D_{t+1})$ plots the steady state debt limit for each values of D_{t+1}.

level.[13] Intuitively, the minimum level of D_t such that the equilibrium borrowing limit curve is tangent to the 45-degree line in Figure 13 would increase as the DNDF settlement monotonically increases the borrowing limit.

Figure 14 shows that DNDF settlement raises the minimum initial debt at which crisis equilibria appear in this numerical example.[14] For debt between the laissez faire and insured thresholds, the settlement eliminates the crisis equilibrium. At higher debt, comparisons of the worst crisis equilibria apply over the range where both the insured and laissez faire equilibria are plotted.

We have shown so far that the simple DNDF policy in a deterministic environment can contribute to preventing a self-fulfilling crisis when the initial debt is not too high. Over the common range shown in Figure 14, the settlement supports tradable consumption and reduces the severity of the worst crisis. This comparison concerns payments on contracts issued in the previous period. Section 5 studies how the announcement of insurance affects

[13] When the boundary of the crisis region arises through an interior tangency, it satisfies $\overline{d}(D_{t+1}; D_t) = D_{t+1}$ and $\partial \overline{d} / \partial D_{t+1} = 1$. Convexity and the relevant boundary conditions must be verified to interpret this tangency as a threshold. Appendix C.3 gives the local conditions.

[14] We confirm that the results are qualitatively similar when we impose an alternative borrowing constraint for the households in which debt is limited to a fraction of the sum of households' total income including profits distributed by financial intermediaries. Higher θ raises the minimum initial debt at which a self-fulfilling crisis appears.

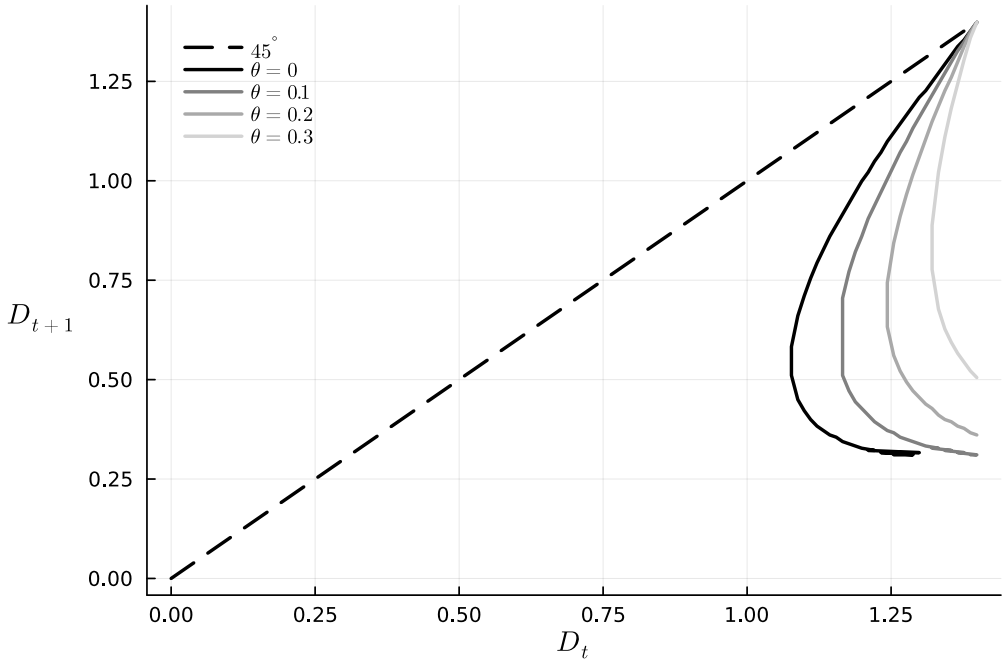


FIGURE 14. Effect of DNDF Policy on Equilibrium Debt $D_{t+1}(D_t)$ in Self-fulfilling Crisis

Note. The curves plot equilibrium debt for $\theta = 0, 0.1, 0.2$, and 0.3. The numerical example uses $R = 1.04$, $\beta = 1/R$, $\chi = 0.1$, $\gamma = 0.4$, $\phi = 0.2$, $\kappa = 0.3$, and $y^T = 1$. Money supply is constant at the initial steady state level.

expected lending and exchange rates at issuance, as well as subsequent crisis risk.

4.3 Comparison to Capital Controls

We now consider an alternative environment where the central bank taxes new external borrowing. The tax is collected from loan proceeds in period t and rebated lump sum in the same period. We express the tax as $\tau_t \geq 0$, so that the private borrowing cost is multiplied by $1 + \tau_t$ and households retain $1/(1 + \tau_t)$ of the loan proceeds before the lump-sum rebate. The representative household's budget constraint becomes

$$p_t^T c_t^T + p_t^N c_t^N + e_t d_t + M_{t+1} = p_t^T y^T + w_t h_t + \frac{e_t d_{t+1}}{R(1+\tau_t)} + M_t + T_t. \tag{35}$$

Here deterministic interest parity implies debt repayment of $e_t d_t$ and zero intermediary profits. T_t denotes a lump-sum transfer in this subsection. Households take the transfer as given when choosing borrowing. The Euler equation is

$$(1 - \mu_t) u_T(t) = \beta R(1 + \tau_t) u_T(t+1), \tag{36}$$

where the borrowing constraint multiplier is normalized by the marginal value of after-tax loan proceeds. Thus, as with DNDF provision, the policy affects current borrowing through the Euler equation. The difference is that tax collection and redistribution take place

immediately, whereas a DNDF issued in period t settles in period $t+1$.

The central bank sets money supply M_{t+1} and the current borrowing tax. With aggregate borrowing D_{t+1}, the contemporaneous rebate is

$$T_t = (M_{t+1} - M_t) + \frac{\tau_t}{1+\tau_t}\frac{e_t D_{t+1}}{R}. \tag{37}$$

In a symmetric equilibrium, collection and rebate cancel in the aggregate resource constraint. The tax changes the private marginal incentive to borrow without transferring net resources across periods or leaving a state-contingent public claim for the next period.

We can define the competitive equilibrium of this economy under any sequence of tax rates as follows.

Definition 2 (Equilibrium under Capital Control)**.** *Given initial conditions $\{w_{-1}, d_0\}$ and an arbitrary sequence of $\{\tau_t, M_t\}_{t=0}^{\infty}$, the competitive equilibrium is defined as a sequence of allocations $\{c_t^T, c_t^N, c_t, h_t, d_{t+1}, \mu_t\}_{t=0}^{\infty}$, prices $\{e_t, p_t^N, p_t, w_t, \tilde{R}_t\}_{t=0}^{\infty}$, and $\{T_t\}_{t=0}^{\infty}$ such that*

1. *Given initial debt d_0, tradables endowment y^T, prices, and policy $\{\tau_t, T_t\}_{t=0}^{\infty}$, households maximize their lifetime utility and firms maximize profit each period.*
2. *The lump-sum transfer T_t satisfies (37) each period.*
3. *Markets clear.*

We consider the steady state equilibrium when $\beta R = 1$ and y^T is constant over time as in the baseline model. At the steady state, money supply is constant and $\tau_0 = \tau_t = 0$ so that the government does not transfer resources to the households.

We have shown that the DNDF policy can effectively mitigate the self-fulfilling crisis with Remarks 1 and 2. We now show that capital controls can be used to eliminate the sunspot equilibrium and ensure that the borrowing constraint never binds in the deterministic environment.

We consider a deterministic environment where the economy has been at the steady state until period $t-1$, as in Section 4, but with one modification. The central bank chooses τ_t in period t, so the economy can deviate from the steady state depending on its choice. However, we impose that the full employment equilibrium is implemented at period $t+1$ without the self-fulfilling crisis, and the allocation stays constant from period $t+2$ and henceforth. Also, the central bank adjusts the money supply at period $t+1$ to satisfy the money demand equation in period $t+1$. Since the tax is collected and rebated in period t, continuation consumption is $y^T - (R-1)D_{t+1}/R$ without an additional tax term. In this scenario, the central bank can eliminate the self-fulfilling crisis at period t by imposing the following rule.

Remark 3. *Given initial aggregate debt D_t, the central bank can eliminate the crisis equilibria by announcing the policy rule $\mathcal{T}(D_{t+1}, D_t)$ that satisfies*

$$u_T\left(y^T + \frac{D_{t+1}}{R} - D_t, \bar{h}\right) = (1 + \mathcal{T}(D_{t+1}, D_t))\, u_T\left(y^T - \frac{R-1}{R} D_{t+1}, \bar{h}\right), \tag{38}$$

when $D_{t+1} \leq D_t$ and consumption is positive. The tax is taken as given by each individual and depends on aggregate borrowing.

Proof. See Appendix C.4. ■

The tax schedule changes households' borrowing incentives at every proposed crisis allocation. Because the tax reduces the proceeds from an additional loan, a household at the prices associated with that allocation prefers to borrow less than the amount needed to sustain the anticipated aggregate outcome. Desired borrowing therefore fails to validate the proposed crisis. The initial full employment allocation remains an equilibrium with a zero tax. The effectiveness of this commitment comes from making the tax depend on aggregate borrowing, as in the coordination policies studied by Schmitt-Grohé and Uribe (2021) and Bianchi and Coulibaly (2026). It does not require a net transfer of resources to households since the tax revenue is rebated in the same period.

The commitment in equation (38) can respond to every possible level of aggregate borrowing. An announced tax rate, held fixed before households coordinate, has less scope to change their incentives across these outcomes. This distinction motivates the quantitative comparison that follows. We let the central bank commit to either a DNDF rate or a borrowing tax before the realization of the sunspot and examine how insurance and the incentive to limit debt affect current activity, future crises, and welfare.

5 Numerical Analysis

We compare a one-period DNDF program with a tax on new borrowing in the stochastic economy. The comparison includes settlement and fiscal adjustment, accounting for the additional private debt and public liabilities created by insurance. We evaluate the policies in states drawn from the stationary laissez faire distribution and in states where high outstanding debt forces a contraction in economic activity.

5.1 Calibration

We calibrate the model to the Mexican economy at an annual frequency. We set $u(c) = \log c$ and $v(m) = \chi \log m$ with $m \equiv \frac{M}{p}$ and $\chi = 0.1$. The elasticity of substitution and the tradable consumption weight are $\gamma = 0.5$ and $\phi = 0.32$, following Schmitt-Grohé and Uribe (2021). Labor supply is normalized to $\overline{h} = 1$ and nominal wages satisfy $w_t \geq 0.96 w_{t-1}$. The collateral parameter is $\kappa = 0.38$. Money supply is fixed at $\overline{M} = 1$, so the exercise isolates forward insurance from changes in monetary policy.

The exogenous processes are

$$\log y_t^T = 0.186 \log y_{t-1}^T + \epsilon_t^y, \qquad \sigma_y = 0.0182, \tag{39}$$

$$\log(R_t/1.00834) = 0.6542 \log(R_{t-1}/1.00834) + \epsilon_t^R, \qquad \sigma_R = 0.012. \tag{40}$$

The parameters are estimated from the cyclical component of Mexican real GDP and the federal funds rate.[15]

We jointly calibrate the sunspot probability π, discount factor β, and intermediary risk aversion ω to exchange rate volatility, average external debt relative to GDP from Lane and Milesi-Ferretti (2018), and Mexico's average EMBI spread. The model spread compares domestic currency household lending with dollar funding and reflects expected depreciation and intermediary currency risk. We use the dollar-denominated sovereign EMBI spread and economy-wide external debt as aggregate benchmarks for borrowing conditions and indebtedness. Table 2 reports the estimates and model fit under laissez faire. The implied unconditional crisis probability is 0.51%. Appendix D describes the numerical methods.

TABLE 2: Calibration and Targeted Moments

Parameter	Value	Target	Model	Data
Sunspot probability (π)	0.2094	SD of annual $\Delta \log e$	0.0914	0.0914
Time discount factor (β)	0.9689	Average debt/GDP	0.3379	0.3240
Intermediary's risk aversion (ω)	18.84	Average spread	0.0206	0.0216

Notes. The three parameters are estimated jointly using all three moments. The model spread is $\tilde{R}_t/R_t - 1$.

5.2 Policy Design and Timing

We study the effects of an unexpected DNDF policy that occurs for one period. The policy exercise runs for four periods. The economy is at the laissez faire equilibrium at period 1. At the beginning of period 2, after observing (d_2, w_1, y_2^T, R_2) but before the sunspot ι_2, the central

[15] The source series are NGDPRSAXDCMXQ and FEDFUNDS from FRED. We linearly detrend real GDP to compute the cyclical component.

bank chooses a forward rate f_2 or abstains from intervention. We denote this announcement stage as 2a. At stage 2b, the sunspot is realized, intermediaries choose their hedge ratio $\theta_2 \in [0,1]$, and households choose borrowing d_3. The contract settles in period 3, with no new issuance. In period 4, the central bank closes its position through a lump-sum transfer or tax, and the economy continues without intervention with net debt $d_4 - a_4$.

The central bank begins with zero assets and can finance settlement losses until period 4 because its borrowing limit does not bind. Households ultimately bear these losses through the fiscal adjustment. Forward supply is uncapped in this exercise. Mexico's program had a USD 20 billion notional ceiling.

Let $U^{\mathrm{LF}}(d, w_-, y^T, R)$ denote expected household lifetime utility under laissez faire, after observing fundamentals but before the current sunspot, where w_- is the previous period's nominal wage. Given the announcement state $x = (d_2, w_1, y_2^T, R_2)$, the central bank maximizes household welfare by solving

$$U_2^{\mathrm{DNDF}}(x) = \max_{f_2} \mathbb{E}_{2a}\left[u(c_2) + v\left(\frac{\overline{M}}{p_2}\right) + \beta U_3(d_3, w_2, y_3^T, R_3; \theta_2, f_2) \,\middle|\, x, f_2\right], \tag{41}$$

and the continuation value at settlement is

$$U_3(d_3, w_2, y_3^T, R_3; \theta_2, f_2) = \mathbb{E}\left[u(c_3) + v\left(\frac{\overline{M}}{p_3}\right) + \beta U^{\mathrm{LF}}(d_4 - a_4, w_3, y_4^T, R_4)\right]. \tag{42}$$

The settlement position a_4 enters the continuation value through net debt after fiscal adjustment. From period 4 onward, the laissez faire value satisfies

$$U^{\mathrm{LF}}(x) = \mathbb{E}\left[u(c) + v\left(\frac{\overline{M}}{p}\right) + \beta U^{\mathrm{LF}}(x') \,\middle|\, x\right], \tag{43}$$

where $x' = (d', w, y^{T\prime}, R')$ is the next state under laissez faire.

The capital control is chosen at stage 2a using the same information. The tax τ_2 raises the private borrowing cost by a factor of $1 + \tau_2$, with collection and the lump-sum rebate at stage 2b. The policy problem maximizes over τ_2 and replaces U_3 in equation (41) with $U^{\mathrm{LF}}(d_3, w_2, y_3^T, R_3)$ since the economy returns to laissez faire in period 3 without a public position. Unlike the state-contingent commitment in Section 4.3, the announced tax cannot adjust to aggregate borrowing. Figure 15 summarizes the timing.

5.3 Effect of Policy Announcement

To relate the exchange rate response to consumption, we substitute $\gamma = 1/2$ and the nontradable market clearing condition $c_t^N = h_t$ into the consumption index (5). Composite

	Period 1	Period 2		Period 3	Period 4
	Before policy	2a Announcement	2b Implementation	Settlement	Fiscal adjustment
	Common history	Fundamentals observed	Sunspot realized	New shocks	New shocks
DNDF	Laissez faire	Choose f_2 or abstain	Choose θ_2 Issue contract	Contingent payment	Tax or transfer closes position
Capital Control	Laissez faire	Choose tax	Lump-sum rebate	Laissez faire	Laissez faire

FIGURE 15. Timing of the Policy Experiments

consumption and the marginal utility of tradable consumption are obtained as

$$c_t = \left(\frac{\phi}{c_t^T} + \frac{1-\phi}{h_t} \right)^{-1}, \qquad u_T(t) = \frac{\phi h_t}{c_t^T [\phi h_t + (1-\phi) c_t^T]}. \tag{44}$$

With logarithmic utility from real money balances and a fixed money supply, the money demand condition (9) becomes

$$\frac{u_T(t)}{e_t} = \frac{\chi}{\overline{M}} + \beta \mathbb{E}_t \left[\frac{u_T(t+1)}{e_{t+1}} \right]. \tag{45}$$

Iterating this equation in the bounded solution gives $u_T(t)/e_t = \chi / [\overline{M}(1-\beta)]$. Substituting the marginal utility expression yields

$$e_t = \frac{\overline{M}(1-\beta)}{\chi} \frac{\phi h_t}{c_t^T [\phi h_t + (1-\phi) c_t^T]}. \tag{46}$$

At a given level of employment, higher tradable consumption lowers marginal utility and appreciates the currency. The household Euler equation (10) reduces to $1 - \mu_t = \beta \tilde{R}_t$, so the nominal lending rate is $1/\beta$ when the borrowing constraint is slack. Combining this condition with covered interest parity (21) gives

$$(1-\mu_t) e_t = \beta R_t f_t \quad \text{if } \theta_t > 0, \qquad e_t = \beta R_t f_t \quad \text{if also } \mu_t = 0. \tag{47}$$

We define intervention states as states x in which the chosen DNDF policy offers a forward contract. They account for 38.78% of the stationary laissez faire distribution. We evaluate both policies on this set using the same laissez faire weights. The announcement effect is the change in the conditional expectation of the period-2 exchange rate, which is determined at issuance in stage 2b. For policy j, the expectation at stage 2a is

$$\mathbb{E}_{2a}[e_2^j \mid x] = (1-\pi) e_2^j(x,0) + \pi e_2^j(x,1), \tag{48}$$

where $e_2^j(x,0)$ and $e_2^j(x,1)$ are the exchange rates under normal and pessimistic expectations, respectively. A lower e_2 means appreciation.

TABLE 3: Exchange Rate Effects in Intervention States

	Laissez faire	DNDF	Capital control
Expected exchange rate change in period 2 (%)	0.00	−2.82	+5.05
Exchange rate volatility in period 3 (%)	8.44	4.69	3.33

Notes. Exchange rate changes are relative to laissez faire. Volatility is $100\,\mathrm{sd}_{2a}(\log e_3)$, computed within each initial state using physical probabilities and then averaged.

Table 3 shows that both policies reduce exchange rate risk at settlement, while DNDFs lower the expected exchange rate at issuance.[16] With insurance, intermediaries' required repayment is tied to the forward rate by equation (47). At the selected rate, borrowing and consumption rise, appreciating the currency through equation (46).

With capital controls, the financial intermediaries are uninsured and the household Euler equation becomes

$$(1-\mu_2)e_2 = \beta R_2(1+\tau_2)\left\{\mathbb{E}_2[e_3] + \omega d_3 \,\mathrm{Var}_2(e_3)\right\}. \tag{49}$$

The tax reduces borrowing and current consumption, depreciates the currency, and lowers future crisis risk by leaving less debt to repay. Appendix D.3 reports risk at additional horizons and averages over the full stationary distribution.

5.4 Debt, Crisis Risk, and Welfare

Figure 16 follows the economy from the median intervention state under normal expectations.[17] The DNDF appreciation reverses at settlement as the additional debt comes due. The tax leaves less debt to repay, supporting consumption and the currency in the following period.

DNDF settlements sustain consumption and collateral in depreciation states, sharply reducing crisis risk in period 3 (Table 4). In period 2, the pessimistic equilibrium remains unchanged because intermediaries choose no coverage in that outcome. Period-2 crisis risk is consequently unchanged, and exchange rate volatility rises (Table A4). After coverage expires, the additional debt and fiscal burden raise crisis risk above laissez faire, although the probability of at least one crisis over periods 3–5 remains lower. The tax reduces debt and

[16] Model volatility uses physical probabilities, whereas the empirical evidence measures risk-neutral implied volatility. The model's settlement horizon is one year, while empirical maturities range from one week to one year.

[17] The median is defined by the debt-to-GDP ratio across intervention states. The mean wage in those states is used to set the initial nominal wage.

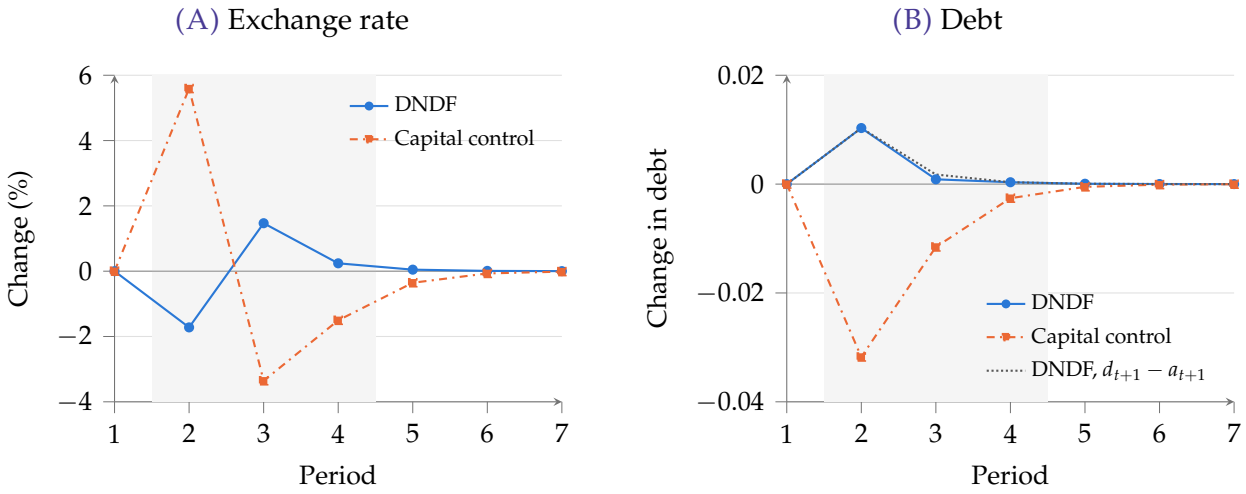


FIGURE 16. Exchange Rate and Borrowing at the Median Intervention State

Notes. Paths are deviations from laissez faire, with median fundamentals and normal expectations throughout. Debt is in units of mean tradable endowment. The dotted debt path is net of central bank assets.

crisis risk both at settlement and afterward.

We evaluate welfare at announcement using expected lifetime utility $U_2^j(x)$, which includes settlement, fiscal adjustment, and subsequent allocations. Gains are expressed as consumption equivalents over periods 2–4.[18]

TABLE 4: Crisis Risk and Welfare in Intervention States (%)

	Laissez faire	DNDF	Capital control
Crisis probability			
Settlement (period 3)	1.054	0.112	0.001
Fiscal adjustment (period 4)	0.748	1.129	0.202
At least one crisis in periods 3–5	2.454	1.965	0.670
Welfare gain relative to laissez faire	—	0.028	0.074

Notes. A crisis has a positive borrowing constraint multiplier. Welfare gains are consumption equivalents from equation (50).

Capital controls yield larger average welfare gains in these states, where the borrowing constraint is usually slack at implementation. The tax reduces debt before adverse shocks force a contraction, leaving more resources to absorb future losses.

[18]The consumption equivalent $\lambda_{2:4}^j(x)$ is the proportional increase in laissez faire consumption during periods 2–4 that matches policy j's lifetime utility, holding real money balances and later consumption at their laissez faire levels. With logarithmic utility,

$$\lambda_{2:4}^j(x) = \exp\left\{\frac{U_2^j(x) - U^{\mathrm{LF}}(x)}{1+\beta+\beta^2}\right\} - 1. \tag{50}$$

5.5 DNDFs and Capital Controls in States with High Debt

The welfare ranking reverses in the three high-debt states in Table 5.[19] In each state, the borrowing constraint binds in every laissez faire equilibrium, including under normal expectations. The table reports current consumption under normal expectations ($\iota_2 = 0$) and expected welfare gains.

TABLE 5: Policy Effects in States with High Debt

Initial debt/GDP	0.812	0.917	1.011
Tradable consumption c_2^T			
Laissez faire	0.391	0.311	0.247
DNDF	0.925	0.981	1.029
Expected welfare gain (%)			
DNDF	10.51	14.60	18.66
Capital control	0	0	0

Notes. Initial debt/GDP is measured under laissez faire and normal expectations. Consumption is in units of mean tradable endowment. Welfare gains use equation (50) and include both sunspot outcomes.

Debt repayment already forces a contraction in these states, making additional borrowing valuable for current consumption. A capital control tax would deepen the contraction, and the chosen tax is zero in all three cases.

Under DNDFs, intermediaries fully hedge, tying loan repayments to the selected forward rate. Lending and consumption rise, while appreciation raises the dollar value of nontradable income and expands collateral. Full employment is restored under normal expectations, although the borrowing constraint remains binding. The welfare gains evaluate this forward offer together with deferred public financing and include the subsequent fiscal adjustment.

6 Concluding Remarks

Mexico's DNDF announcements in 2017 were accompanied by an appreciation of the peso and declines in option implied volatility and depreciation risk. The volatility response was concentrated at short maturities. The subsequent auctions produced no statistically significant additional effects. We interpret these effects as a result of the policy announcements changing private agents' expectations.

In the model, an announced forward offer changes lending terms by protecting intermediaries against future depreciation. Additional lending sustains consumption and nontradable income, while appreciation raises the dollar value of collateral. The quantitative exercise produces an expected appreciation at issuance and lower exchange rate risk at settlement.

[19] Fundamentals are set at their medians. The mean wage in the stationary laissez faire distribution is used to set the initial nominal wage.

The current pessimistic equilibrium remains unchanged. Crisis risk rises after insurance expires as the additional debt comes due.

A borrowing tax yields larger average welfare gains in the intervention states drawn from the stationary distribution by limiting debt accumulation. In the high-debt examples, repayment burdens already depress consumption, and a borrowing tax would deepen the contraction. DNDFs instead sustain credit and restore full employment under normal expectations. These gains include both the protection and lending terms provided by the forward offer, with settlement financed publicly until the fiscal adjustment.

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Appendix A Bank of Mexico Press Release

"On February 21, 2017, ... the Bank of Mexico, which is responsible for Mexico's foreign exchange policy, announced the implementation of a new foreign exchange market mechanism that consists of non-deliverable forward (NDF's) auctions, which will be settled in *Mexican Pesos*. The mechanism aims to maintain the proper functioning of the local exchange market while supplying market participants with a foreign exchange hedging instrument to mitigate exposure to FX risk. The most important operational details of the mechanism are summarized below:

1. The program can size up to 20 billion US dollars taking into consideration the total nominal amount outstanding.
2. The maximum tenor of the NDF's will be 12 months.
3. Since the settlement of the forward is non-deliverable, the stock of international reserves is unaffected by the sale of these instruments.
4. Only local banks that can operate derivatives are allowed to present tenders.
5. Auctions will be interactive, will last two minutes, and the allotment will be done at multiple price.
6. The Bank of Mexico will roll over the total amount outstanding of the NDFs until the Foreign Exchange Commission deems it necessary.
7. The first auction will take place on March 6, 2017, for a total notional amount of one billion USD distributed across six maturities.

On March 6, 2017, the first Foreign Exchange hedge auction was held for an amount of one billion USD divided into six terms."

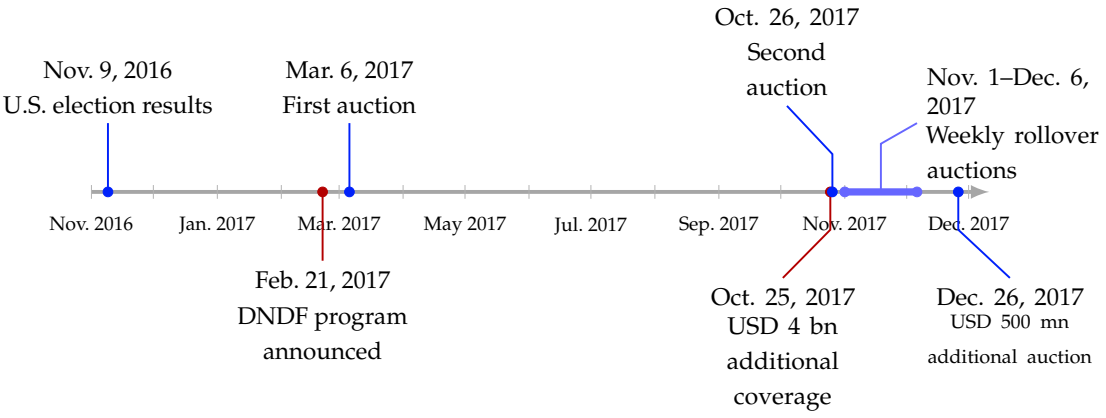


FIGURE A1. Timeline of Announcements and Auctions

Note: Subsequent announcements increased auctioned coverage by USD 4 billion and USD 500 million within the original program limit.

Appendix B Additional Empirical Evidence

This appendix collects exercises that focus on the level of the exchange rate and the forward premium, which we treat as complementary evidence, along with the methodology behind the risk-neutral depreciation probabilities reported in Section 2.

B.1 Exchange Rate Level: High-Frequency Event Study

To quantify the response of the level of exchange rate to each event, we estimate the following model on intraday data,

$$y_t = \alpha + \rho t + \sum_{s=-\tau}^{\tau} \beta_s \mathbb{1}\{t = T_0 + s\} + \theta\, VIX_t + \varepsilon_t, \tag{B.1}$$

where y_t is the tick-by-tick peso-dollar exchange rate, t is a linear trend, $\mathbb{1}\{\cdot\}$ indicates the s ticks before and after the event T_0, VIX_t controls for global volatility, and ε_t is the error term. In the baseline, we set $\tau = 10$ so that we examine ten ticks before and after each event using the two days on either side. When the timestamps of the exchange rate and the VIX do not coincide, we take the VIX value at the nearest available timestamp.

Figure B1 reports the estimates of β_s. Panel B1A shows an average effect of 32.91 cents associated with the first announcement, and this estimate is robust to the choice of window τ and to additional controls such as the price of gold and the Euro Stoxx 50 volatility index.[20] Panel B1B shows no effect associated with the first auction. Panels B1C to B1F report the estimates for the subsequent events, with significant effects at the announcements of the program extensions and no significant effects at the auctions. This mirrors the announcement and implementation contrast documented for volatility in the main text.

B.2 Forward Premium

We next study the response of the implied forward premium in cross-currency swaps, using the data of Du and Schreger (2016) for maturities of 3 months, 1 year, 2 years, 3 years, 5 years, 7 years, and 10 years. Given the results on the exchange rate and its option implied volatility, we expect the forward premium to fall after the announcements as pressure on the peso eases. Figure B2 plots the daily forward premium by tenor. The contraction is larger at shorter maturities: after the first announcement the 3-month premium fell by about 80 basis points while the 10-year premium fell by about 17 basis points. The premium was also more sensitive to the first announcement than to the later ones, plausibly because markets came to

[20] We use the price of gold in U.S. dollars as an additional control because tick-level oil prices are unavailable for this period.

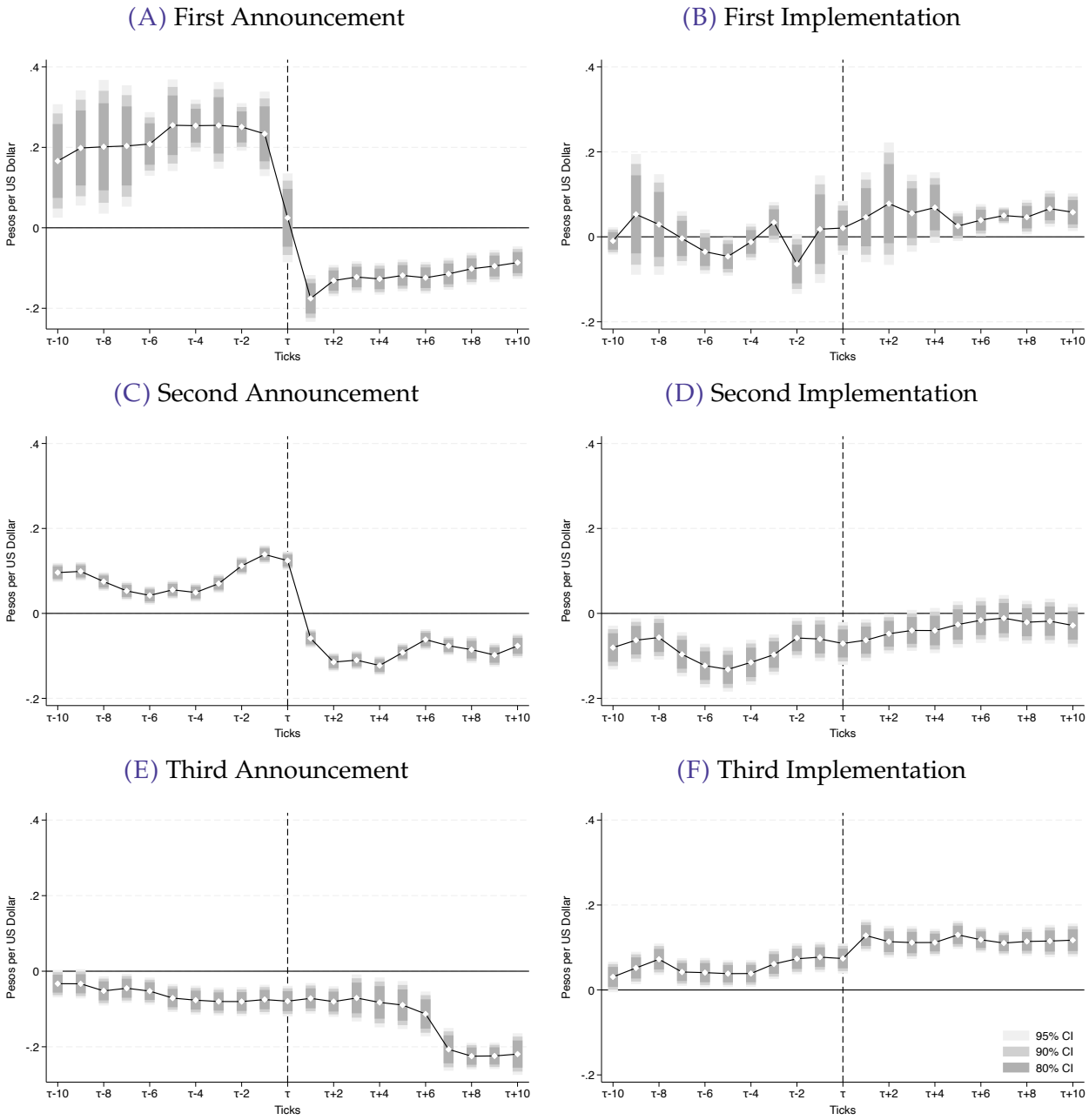


FIGURE B1. Effect of DNDF on the USD/MXN Level: Announcements and Implementations

Note: Diamonds are the point estimates of β_s; shaded areas are the 80%, 90%, and 95% confidence intervals from heteroskedasticity and autocorrelation robust standard errors.

anticipate the subsequent interventions given the ongoing pressure on the peso.[21]

[21] During the second half of 2017 there were several rounds of NAFTA renegotiation, further Fed funds rate hikes, and the approval of the U.S. fiscal reform.

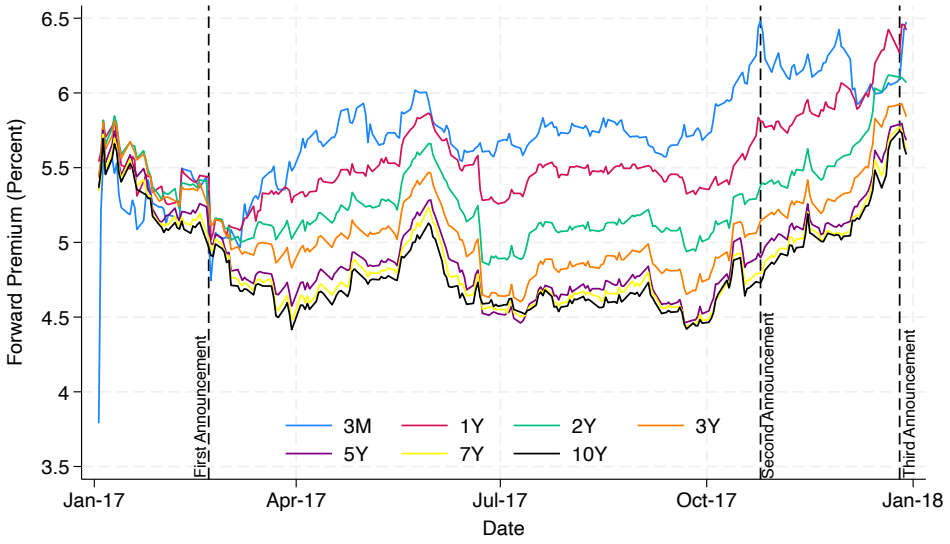


FIGURE B2. Forward Premium by Maturity

Note: Own elaboration with data from Du and Schreger (2016). The first announcement is February 21, 2017; the second and third are October 25, 2017 and December 26, 2017.

TABLE B1: Effect of DNDF on the Forward Premium

Variable	Pooled			Panel		
	(1)	(2)	(3)	(4)	(5)	(6)
Lagged premium	0.985***	0.983***		0.984***	0.982***	
	(0.003)	(0.003)		(0.002)	(0.003)	
Linear time trend	0.0001***	0.0001***		0.0001**	0.0001	
	(0.0000)	(0.0000)		(0.0000)	(0.0000)	
Announcement	-0.064*	-0.065*	-0.064	-0.064**	-0.066**	-0.065*
	(0.038)	(0.038)	(0.039)	(0.024)	(0.024)	(0.026)
Implementation	0.020***	0.015**	0.022***	0.014**	0.014**	0.022***
	(0.006)	(0.006)	(0.006)	(0.004)	(0.004)	(0.004)
Lagged Change Mon. Pol.		0.001***	0.001***		0.001**	0.001***
		(0.0002)	(0.0002)		(0.0002)	(0.0001)
VIX Index		0.002***	0.002***		0.002***	0.002***
		(0.0005)	(0.0005)		(0.0005)	(0.0003)
Oil Prices (WTI)		0.001**	0.0007**		0.001***	0.0007***
		(0.0004)	(0.0003)		(0.0002)	(0.0001)
Daily Change in Fed Funds Rate		0.001**	0.0007**		0.0007***	0.0007***
		(0.0003)	(0.0003)		(0.0000)	(0.0000)
Constant	✓	✓	✓	✓	✓	✓
Fixed Effects				✓	✓	✓
Obs.	2,708	2,708	2,708	2,708	2,708	2,708
R^2	0.993	0.993	0.029	0.999	0.999	0.061

Note: The R^2 for the panel specifications is the within measure. ***, **, * denote significance at 1%, 5%, and 10%. Robust standard errors in parentheses.

Estimating the panel specification of the main text with the forward premium as the dependent variable (Table B1) confirms the pattern: the announcement lowered the premium by

about 6 basis points, while the auctions are associated with a small increase of about 2 basis points.

B.3 Synthetic Controls

Let $\mathbb{Y}_1$ be a vector of dimension $(T \times 1)$ that contains the outcome variable of interest for Mexico with $1 \leq T_0 < T$ where T_0 denotes the number of pre-intervention periods and let $\mathbb{Y}_0$ be a matrix of dimension $(T \times J)$ that has the same outcome variable for the countries in the donor pool. In addition, let $\mathbb{X}_1$ denote a vector of dimension $(K \times 1)$ with K different predictors of the outcome variable for Mexico and let $\mathbb{X}_0$ denote a matrix of dimension $(K \times J)$ with the same predictors for the J countries in the donor pool. Also, let $\mathbb{W}$ be a vector of weights of dimension $(J \times 1)$ and $\mathbb{V}$ a diagonal matrix with non-negative values of dimension $(K \times K)$.

The objective of the method is to find the weights $\mathbb{W}^\star$ that allow us to match the pre-treatment characteristics of the treated unit. In other words, we need to solve the following minimization problem:

$$\min_{\mathbb{W} \in \mathcal{W}} ||\mathbb{X}_1 - \mathbb{X}_0 \mathbb{W}||_{\mathbb{V}}^2 = \min_{\mathbb{W} \in \mathcal{W}} \left(\mathbb{X}_1 - \mathbb{X}_0 \mathbb{W}\right)^T \mathbb{V} \left(\mathbb{X}_1 - \mathbb{X}_0 \mathbb{W}\right), \tag{B.2}$$

where

$$\mathcal{W} = \left\{ (w_2, \ldots, w_{J+1}) \middle| w_j \geq 0 \text{ and } \sum_{j=2}^{J+1} w_j = 1 \right\}, \tag{B.3}$$

is the set of all non-negative weights that sum up to one. From the previous optimization problem, we can see that the solution for the weight vector will depend on our choice of the symmetric and positive semidefinite matrix $\mathbb{V}$. As in Abadie and Gardeazabal (2003), we choose the value of $\mathbb{V}$ such that it minimizes the mean squared prediction error of the outcome variable for the pre-intervention period:

$$\mathbb{V}^\star = \arg\min_{\mathbb{V} \in \mathcal{V}} \left(\mathbb{Z}_1 - \mathbb{Z}_0 \mathbb{W}^\star(\mathbb{V})\right)^T \left(\mathbb{Z}_1 - \mathbb{Z}_0 \mathbb{W}^\star(\mathbb{V})\right), \tag{B.4}$$

where $\mathbb{Z}_1$ is a vector of dimension $(T_0 \times 1)$ that contains the pre-treatment observations of the outcome variable for the treated unit (i.e., Mexico), $\mathbb{Z}_0$ is a matrix of dimension $(T_0 \times J)$ with the observations of the outcome variable for the J countries in the donor pool in the pre-intervention sample, and $\mathcal{V}$ is the set of all non-negative diagonal matrices. The optimal weights are then given by $\mathbb{W}^\star = \mathbb{W}^\star(\mathbb{V}^\star)$ and, thus, the synthetic counterfactual is given by $\mathbb{Y}_0 \mathbb{W}^\star$. Then, we say that the estimator of the treatment effect is given by:

$$\hat{\alpha}_t = Y_{1,t} - \sum_{j=2}^{J+1} w_j^\star Y_{j,t} \quad \text{for } t \in \{T_0 + 1, \ldots, T\}. \tag{B.5}$$

B.3.1 Exchange Rate Level

As a counterfactual-based complement to the high-frequency design, we apply the synthetic control method to the level of the peso around the first announcement. The framework above defines the synthetic comparison. We first report the results for the exchange rate level, then examine robustness and placebo inference in Section B.3.2. Figure B3 shows the observed

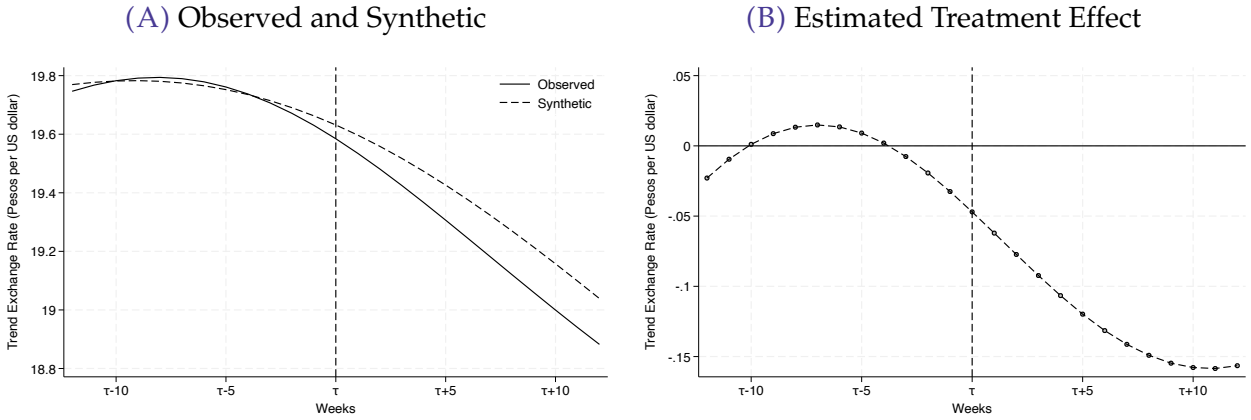


FIGURE B3. Mexican Peso per U.S. Dollar Exchange Rate

Note: Solid and dashed lines are the observed outcome and the synthetic control. t is the week of the announcement. Countries with strictly positive weights are the Czech Republic ($w^\star = 78.30\%$), Poland ($w^\star = 8.40\%$), and South Africa ($w^\star = 13.30\%$).

and synthetic USD/MXN exchange rate and the estimated treatment effect up to twelve weeks after the announcement. The synthetic control for the peso assigns positive weights to only three currencies, the Czech koruna, the South African rand, and the Polish złoty, and the peso appreciates by about 15 cents per dollar three months after the announcement. The apparent separation a few weeks before the announcement is driven by the HP filter used to smooth the series; in Section B.3.2 we show that using the three-month percentage change in the exchange rate as the outcome, the synthetic control separates from the observed series only after the announcement week, which is consistent with an unanticipated policy announcement.

TABLE B2: Trend Exchange Rate Predictor Means

Variables	Observed	Synthetic	Average
3 month option implied volatility	15.14	11.70	9.47
Stock returns	-1.20	3.71	3.84
Risk reversal	2.02	1.88	1.83
Equity flows by mutual funds and ETFs	18.42	8.06	-0.80
Equity flows by II.	26.54	9.98	12.19
Bond flows by mutual funds and ETFs	49.32	8.30	10.22
Bond flows by II.	48.21	7.39	16.75
Outcome variable at $t = 1$	19.75	19.78	32.99
Outcome variable at $t = T_0/2$	19.78	19.78	33.05
Outcome variable at $t = T_0 - 1$	19.63	19.67	33.04

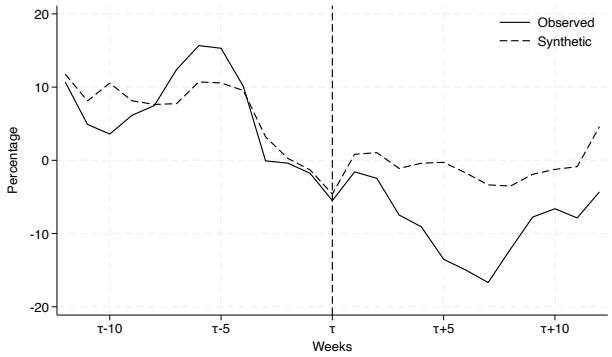
Note: Pre-treatment means of the predictors of the trend exchange rate. The pre-treatment sample is December 1, 2016 to February 16, 2017. ETF stands for exchange-traded funds. T_0 is the week of the announcement.

Table B2 compares the pre-treatment predictors for Mexico, the synthetic control, and a simple average of the donor pool, and the synthetic control matches Mexico more closely than the simple average. The placebo inference in Section B.3.2 places the ratio of posttreatment to pretreatment RMSPE for Mexico among the highest in the donor pool, so that the probability of estimating a gap of this magnitude under a random permutation of the intervention is about 15%. We regard the level result as complementary evidence, since the level of a floating exchange rate cannot be cleanly attributed to a single event over a twelve-week horizon.

B.3.2 Alternative and Robustness

As an alternative to using the HP-filtered exchange rate as the outcome variable, we construct a synthetic counterfactual using the three-month percentage change in the exchange rate as the outcome variable. Figure B4A displays the comparison between the observed three-month percentage change in the exchange rate and the synthetic counterfactual, while figure B4B presents the dynamic treatment effect. Also, in Table B3 we present the comparison between the pre-treatment characteristics of the treated unit, the synthetic control, and the ones associated with a simple average.

(A) Observed and synthetic



(B) Estimated treatment effect

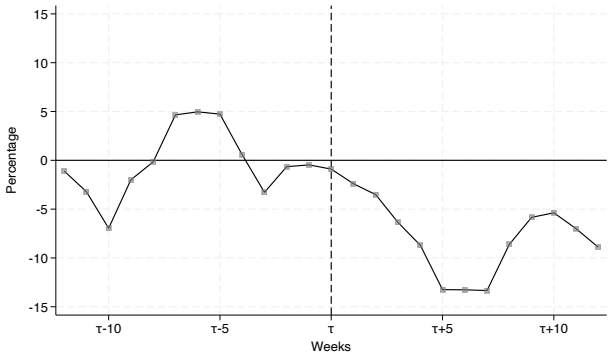


FIGURE B4. 3-month Percentage Change of the Nominal Exchange Rate

Note: The solid line corresponds to the observed outcome variable while the dashed line is the synthetic control. τ corresponds to the week in which the policy was announced by the Bank of Mexico. Countries with strictly positive weights are: Brazil ($w_2^\star = 43.0\%$), Turkey ($w_3^\star = 48.10\%$), and India ($w_4^\star = 8.90\%$).

TABLE B3: Percentage Change in the Exchange Rate Predictor Means

Variables	Observed	Synthetic	Average
3 month option implied volatility	15.14	15.10	9.47
Stock returns	-1.20	2.96	3.84
Risk reversal	2.02	2.99	1.83
Equity flows by MF and ETFs	18.42	64.66	-0.80
Equity flows by II.	26.54	73.07	12.19
Bond flows by MF and ETFs	49.32	34.47	10.22
Bond flows by II.	48.21	34.89	16.75
Outcome variable at $t = 1$	10.69	11.78	4.85
Outcome variable at $t = T_0/2$	15.67	10.70	2.56
Outcome variable at $t = T_0 - 1$	-1.77	-1.30	-2.66

Note: This table displays the pre-treatment mean of the predictors of the outcome variable (i.e., the three-month percentage change in the nominal exchange rate). The pre-treatment sample goes from December 1, 2016, to February 16, 2017. MF and ETF stand for mutual funds and exchange-traded funds, respectively. T_0 corresponds to the week of the announcement.

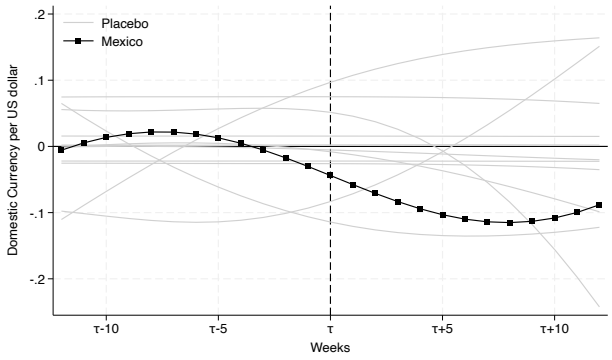
As it is standard in the literature that uses the synthetic control method, we conduct placebo tests following Abadie et al. (2010) by moving Mexico to the donor pool and estimating the synthetic control for the other countries. The placebo exercises show how Mexico's estimated effect compares with the distribution of effects obtained by assigning the intervention to untreated countries. On the one hand, panel B5A from Figure B5 displays the dynamic treatment effect (i.e., the difference between the observed and synthetic outcome variable) for

countries with a pre-treatment Root Mean Squared Prediction Error (RMSPE) of, at most, 5 times the pre-treatment RMSPE of Mexico. The ratio is defined as:

$$Ratio_j = \frac{\sqrt{\frac{1}{T-T_0}\sum_{t=T_0+1}^{T}(Y_{j,t} - \hat{Y}_{j,t})^2}}{\sqrt{\frac{1}{T_0}\sum_{t=0}^{T_0}(Y_{j,t} - \hat{Y}_{j,t})^2}}, \tag{B.6}$$

where $\hat{Y}_{j,t}$ corresponds to the synthetic counterfactual for country j. After the announcement of the policy, Mexico displays one of the largest treatment effects. On the other hand, panel B5B displays the ratio of posttreatment to pretreatment RMSPE using the trend exchange rate as the outcome variable for Mexico and all countries in the donor pool, where we can observe that Mexico has one of the highest ratios, meaning that estimating a gap of the magnitude of the one of Mexico under a random permutation of the intervention is around 15%.

(A) Placebo runs



(B) Post-Pre-Treatment RMSPE Ratio

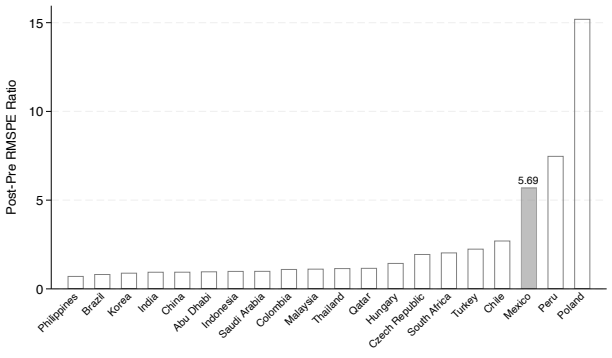


FIGURE B5. Economic and Statistical Significance for Baseline Estimation

Note: The first panel displays the dynamic treatment effect for countries with a pre-treatment RMSPE of at most 5 times the pre-treatment RMSPE of Mexico. The bars represent the ratio of posttreatment to pretreatment RMSPE for Mexico and all other countries in the donor pool.

Regarding the estimates using the three-month percentage change in the USD/MXN nominal exchange rate, in panel B6A from Figure B6, we display the placebo runs for all countries in the donor pool. In this case, Mexico has one of the largest treatment effects, about 10 pp at three months after announcement; however, the pre-treatment fit is worse than the one observed from the baseline estimation where we use the trend exchange rate as the outcome variable. In terms of statistical significance, panel B6B displays the corresponding ratio of posttreatment to pretreatment RMSPE. Relative to the baseline estimates, we find that the effect loses statistical significance since the probability of estimating a gap of the magnitude of Mexico under a random permutation of the intervention is around 33%.

Finally, Figure B7 displays the placebo runs for all countries in the donor pool for each maturity h of the implied volatility of USD/MXN exchange rate options. In terms of the members of the donor pool, we dropped Colombia and South Africa since, for some maturities, there are missing observations. Instead of 19 countries in the donor pool, we now

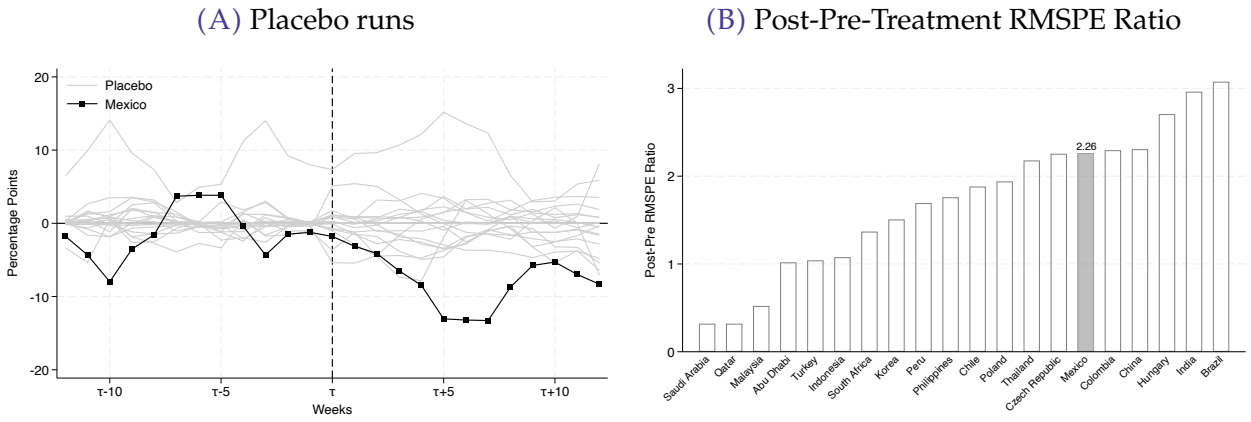


FIGURE B6. Economic and Statistical Significance for Alternative Outcome Variable

Note: The first panel displays the dynamic treatment effect for all countries in the donor pool. The bars represent the ratio of posttreatment to pretreatment RMSPE for Mexico and all other countries in the donor pool.

have 17. We can see that, for very short maturities and near the end of the post-treatment sample, Mexico is in the tail of the empirical treatment distribution. That effect dissipates as we increase the maturity of the financial derivative. Also, we observe that the estimated effect takes more than 3 months to disappear.

B.4 Risk-Neutral Density Extraction

The depreciation probabilities in Section 2.5 are read off the risk-neutral density of the future exchange rate, which we recover from the option implied volatility surface. For each date and maturity we observe the at-the-money volatility, the 25-delta risk reversal, and the 25-delta butterfly, from which we build the volatility smile as a function of the option delta following Malz (1997), and then map the smile from delta space to strike space. Writing $c(K)$ for the undiscounted price of a call struck at K on the forward, the risk-neutral probability of a depreciation beyond K and the risk-neutral density follow from Breeden and Litzenberger (1978),

$$\mathbb{Q}(e_{t+h} > K) = -\frac{\partial c(K)}{\partial K}, \qquad f_{\mathbb{Q}}(K) = \frac{\partial^2 c(K)}{\partial K^2}. \tag{B.7}$$

Using undiscounted call prices gives the probability under the maturity-specific forward measure. We evaluate the strike derivatives on a fine grid and use $\bar{e} = 1.05F_{t,h}$ as the main threshold. The calculation uses only three smile quotes at each maturity, so probabilities away from the quoted strikes depend on the fitted smile. In particular, short-maturity large-depreciation events can require extrapolation beyond the 25-delta wing. The three-month butterfly is interpolated from the two- and six-month quotes. The accompanying code also evaluates thresholds of two, ten, and fifteen percent beyond the forward. These calculations provide sensitivity checks, but a local numerical density check does not establish the absence

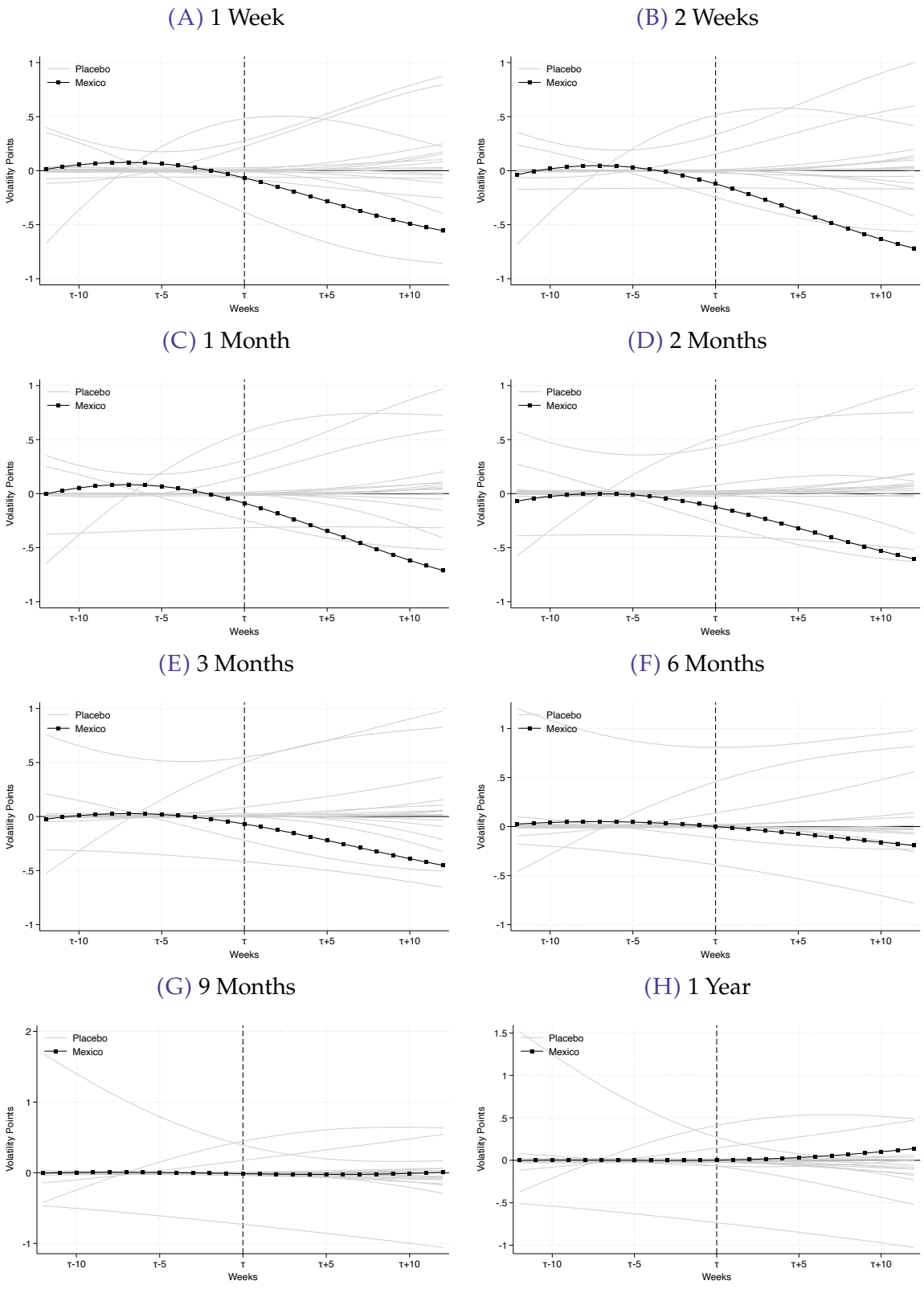


FIGURE B7. Placebo Runs for Implied Volatility

Note: Each panel displays the dynamic treatment effect for all countries in the donor pool using as outcome variable the implied volatility for horizon h. Relative to the donor pool from the baseline estimation, we drop Colombia and South Africa given missing observations for some of the maturities.

of static arbitrage over all strikes. We interpret the resulting probabilities as option implied measures under the stated interpolation and extrapolation assumptions. Their announcement changes combine changes in physical depreciation probabilities and risk prices and are not directly mapped into the structural sunspot probability estimated in Section 5.

B.5 The Second Announcement

The main text reports the risk-neutral depreciation probability response to the first announcement and its auction (Figure 6). Additional auctions were announced twice more within the original program limit. The second announcement occurred on October 25, 2017, with its auction the following day. The third, on December 26, 2017, was announced and auctioned on the same day, so it does not admit the announcement and auction contrast and we omit it. Figure B8 shows that the second announcement reproduces the pattern of the first. The risk-neutral probability of a large depreciation falls across the maturity structure, hump-shaped and largest around the one- to three-month tenors, and the three measures share the broad direction of the response, so the compression does not depend on the symmetric benchmark. The auction the next day shows a reversal of the announcement-day move rather than any further easing, which once more places the effect on the announcement rather than on the provision of the hedges.

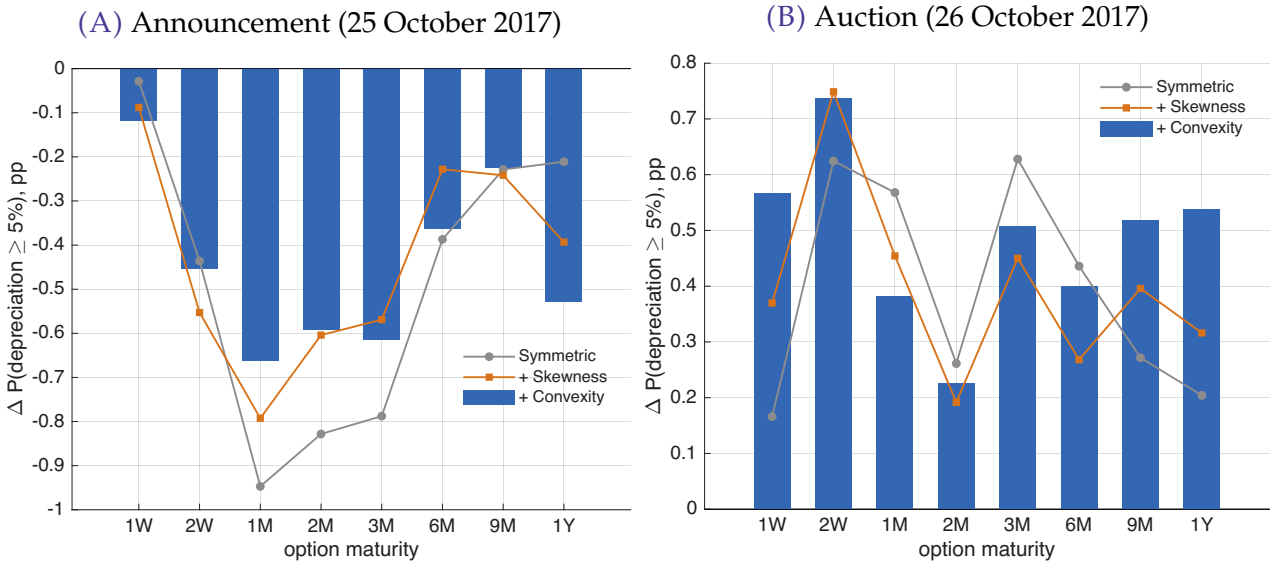


FIGURE B8. The Second Announcement and the Probability of a Large Depreciation

Note: Change in the option implied probability that the peso depreciates by at least five percent beyond the forward, in percentage points, by option maturity, around the October increase in auctioned coverage. "Symmetric" uses the at-the-money volatility only; "+ skewness" adds the 25-delta risk reversal; "+ convexity" adds the 25-delta butterfly. Own elaboration with data from Bloomberg.

B.6 Risk Reversals and Butterflies

The decline in risk-neutral depreciation probabilities documented in Section 2.5 may reflect changes in the asymmetry and curvature of the volatility smile as well as its overall level. To assess these changes while controlling for global factors, we estimate the panel specification of the main text with the 25-delta risk reversal and the 25-delta butterfly as dependent variables. For each object $y \in \{\text{RR}, \text{BF}\}$ and maturity i,

$$y_{i,t} = \rho\, y_{i,t-1} + \omega_1\, \mathbb{A}\{t = T_0\} + \omega_2\, \mathbb{I}\{t = T_1\} + \boldsymbol{\beta}' \boldsymbol{x}_t + \gamma\, z_{t-1} + \varepsilon_{i,t}, \tag{B.8}$$

with the same controls as in (2): $\boldsymbol{x}_t$ collects the VIX, the price of oil, and the daily change in the Fed funds rate, and z_{t-1} is the lagged daily change in Mexico's policy rate. We estimate (B.8) maturity by maturity with Newey-West standard errors robust to serial correlation up to five lags, and we pool the tenors in a panel with maturity fixed effects and Driscoll-Kraay standard errors robust to cross-sectional dependence across the smile.

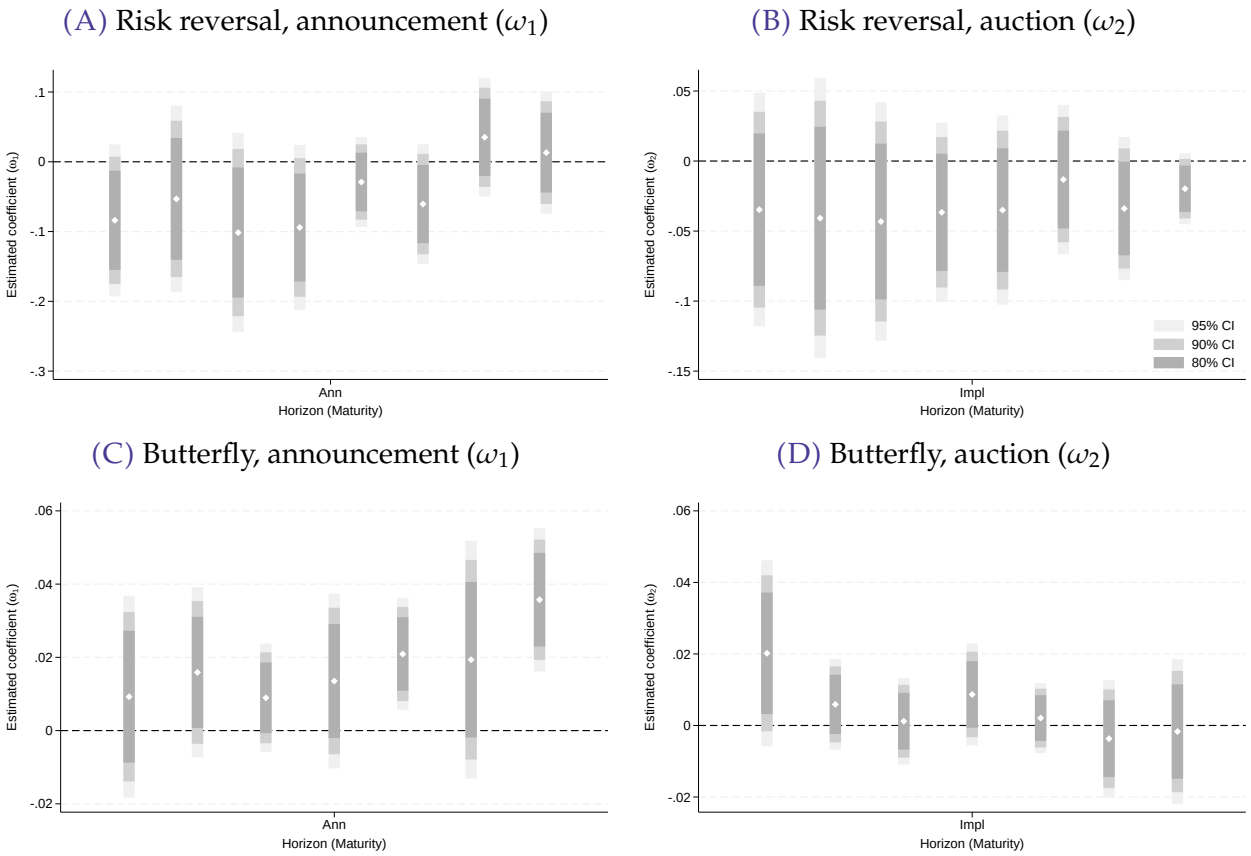


FIGURE B9. Announcement Effects on the Volatility Smile

Note: Estimated announcement (ω_1) and auction (ω_2) coefficients from (B.8), by option maturity, with 80, 90, and 95 percent confidence bands from Newey-West standard errors. The risk reversal measures the asymmetry of the volatility smile and the butterfly its curvature. Own elaboration with data from Bloomberg.

Figure B9 reports the announcement (ω_1) and auction (ω_2) coefficients by maturity. The announcement lowers the risk reversal at short and intermediate maturities, by about one

tenth of a volatility point at the one- and two-month horizons. The effect is at most marginally significant and fades to zero by nine months to one year. The coefficient pooled across maturities is small and not statistically distinguishable from zero. The butterfly coefficient is positive and significant at the six-month and one-year horizons. This increase is consistent with a larger decline in at-the-money volatility than in volatility at the out-of-the-money strikes. The auction coefficients are small and insignificant for both measures at every maturity. These results extend the announcement and auction comparison to the asymmetry and curvature of the volatility smile. Taken together, the estimates suggest that the broad decline in volatility accounts for much of the lower tail probability. They do not separately identify changes in physical depreciation probabilities and risk premia.

Appendix C Proofs and Derivations

C.1 Proof of Remark 1

Consider the deterministic economy in Section 4 with nominal wage w_{t-1}. Let $z = D_{t+1}$, $D = D_t$, $e_0 = e$, and $r = (R-1)/R$. Under full employment from period $t+1$ onward, tradable consumption is $c^s(z) = y^T - rz$. When the wage constraint binds, current tradable consumption and employment satisfy

$$c = y^T + z/R - D + \theta D(1 - e_0/e_t), \tag{C.1}$$

$$h = \left(\frac{1-\phi}{\phi}\frac{e_t}{w_{t-1}}\right)^{\gamma} c. \tag{C.2}$$

Let $\psi = u_T(c,h)c$ denote the share of household expenditure on tradables, and define

$$b = \frac{\theta D e_0}{e_t c}, \qquad L = \gamma + (1-\gamma)\psi + b. \tag{C.3}$$

Under logarithmic CES utility, $\psi = [1 + ((1-\phi)/\phi)^{\gamma}(w_{t-1}/e_t)^{1-\gamma}]^{-1}$. The money demand equation is

$$H(e_t, z) = \frac{u_T(c,h)}{e_t} - \frac{u_N(c^s(z), \bar{h})}{R w_{t-1}} - \frac{\chi}{\overline{M}} = 0. \tag{C.4}$$

Let e_+ denote the exchange rate in the full employment equilibrium from period $t+1$ onward. The household Euler equation is $u_T(c^s(z), \bar{h}) = (1-\mu_t)u_T(c,h)$. Differentiating H gives

$$\frac{\partial e_t}{\partial z} = -\frac{e_t}{Rc}\frac{N}{L}, \qquad N = 1 - r\frac{1-\gamma}{\gamma}\frac{e_t}{e_+}(1-\mu_t)^2\psi. \tag{C.5}$$

Since $\chi/\overline{M} > 0$, the money demand equation implies $(e_t/e_+)(1-\mu_t) < R$. Since $0 \le \mu_t < 1$ and $0 < \psi < 1$, Assumption 1 ensures

$$0 < 1 - (R-1)\frac{1-\gamma}{\gamma} < N \le 1. \tag{C.6}$$

Hence greater borrowing appreciates the currency when the wage constraint binds, $\partial e_t/\partial z < 0$. When employment reaches $\bar{h}$ and the nominal wage remains at w_{t-1}, differentiating the intratemporal condition gives

$$\frac{\partial e_t}{\partial z} = -\frac{e_t}{Rc}\frac{1}{\gamma + b} < 0. \tag{C.7}$$

Starting at the initial steady state, where $z = D$ and $e_t = e_0$, a decline in aggregate borrowing therefore leads to exchange rate depreciation.

C.2 Proof of Remark 2

When the currency depreciates, $e_t > e_0$, the intratemporal condition and $h_t \leq \bar{h}$ imply

$$c_t^T = \left(\frac{\phi}{1-\phi}\frac{w_{t-1}}{e_t}\right)^{\gamma} h_t < \left(\frac{\phi}{1-\phi}\frac{w_{t-1}}{e_0}\right)^{\gamma} \bar{h} = y^T - \frac{R-1}{R} D_t. \tag{C.8}$$

Substituting the resource constraint and multiplying by R yields

$$D_{t+1} < D_t - R\theta D_t \left(1 - \frac{e_0}{e_t}\right), \tag{C.9}$$

which establishes Remark 2.

C.3 Properties of the Equilibrium Borrowing Limit

Let $B = ((1-\phi)/\phi)^{\gamma}(w_{t-1}/e_t)^{1-\gamma} = (1-\psi)/\psi$ denote nontradable expenditure relative to tradable expenditure. The borrowing limit is $\bar{d}(z; D) = \kappa R(y^T + Bc)$. When the wage constraint binds,

$$\frac{\partial \bar{d}}{\partial z} = \kappa B \left[1 + (1-\gamma-b)\frac{N}{L}\right] > 0. \tag{C.10}$$

The derivative is positive if $1-\gamma-b \geq 0$. If $1-\gamma-b < 0$, the result follows from $N \leq 1$ and $L + 1 - \gamma - b = 1 + (1-\gamma)\psi > 0$. At full employment with a fixed nominal wage, N/L is replaced by $1/(\gamma+b)$, and the derivative remains positive.

The forward rate equals the exchange rate in the initial steady state, so a change in initial debt also changes the forward rate. Thus

$$e_0(D) = \frac{\phi}{1-\phi}\left(\frac{\bar{h}}{c^s(D)}\right)^{1/\gamma} w_{t-1}, \qquad e_0'(D) = \frac{r e_0(D)}{\gamma c^s(D)}. \tag{C.11}$$

At a fixed money supply and wage, define $K = 1 - \theta + \theta[e_0(D) + De_0'(D)]/e_t > 0$. Differentiating the money demand equation and the borrowing limit with respect to D gives

$$\frac{\partial e_t}{\partial D} = \frac{e_t K}{cL} > 0, \qquad \frac{\partial \bar{d}}{\partial D} = -\kappa RBK\frac{1 + (1-\gamma)\psi}{L} < 0. \tag{C.12}$$

If the forward rate on the previous period's contract is instead held fixed, the same formulas apply with $e_0'(D) = 0$.

Holding D and the exchange rate fixed, a marginal increase in coverage raises the DNDF payment by $S = D(1 - e_0/e_t) > 0$ when the currency depreciates. Allowing the exchange rate to adjust gives

$$\frac{\partial e_t}{\partial \theta} = -\frac{e_t S}{cL} < 0, \qquad \frac{\partial \bar{d}}{\partial \theta} = \kappa RBS\frac{1 + (1-\gamma)\psi}{L} > 0. \tag{C.13}$$

Greater coverage supports consumption and nontradable income, while the resulting appreciation raises the dollar value of nontradable income. Both effects increase borrowing capacity.

At a tangency between the borrowing limit and the 45-degree line,

$$\bar{d}(z^*; D^*) = z^*, \qquad \frac{\partial \bar{d}(z^*; D^*)}{\partial z} = 1. \tag{C.14}$$

The borrowing limit touches the 45-degree line from above when $\partial^2 \bar{d} / \partial z^2 > 0$.

C.4 Proof of Remark 3

The tax on current loan proceeds is collected and rebated as a lump sum in the same period. With full employment from period $t+1$ onward, consumption is $c^s(z) = y^T - (R-1)z/R$. For $z \leq D$ and positive consumption, consider the tax schedule

$$1 + \mathcal{T}(z, D) = \frac{u_T(y^T + z/R - D, \bar{h})}{u_T(c^s(z), \bar{h})}. \tag{C.15}$$

Since $y^T + z/R - D \leq c^s(z)$ and $u_{TT} < 0$, this rule satisfies $\mathcal{T}(z, D) \geq 0$, with equality at $z = D$. It is continuous wherever consumption is positive.

For logarithmic CES utility with $0 < \gamma < 1$, $u_{TN} > 0$. If a crisis reduces employment below $\bar{h}$, then

$$(1 - \mu_t) u_T(y^T + z/R - D, h_t) \leq u_T(y^T + z/R - D, h_t) < u_T(y^T + z/R - D, \bar{h}). \tag{C.16}$$

By (C.15), the last expression equals $(1 + \mathcal{T}(z, D)) u_T(c^s(z), \bar{h})$, contradicting the household Euler equation for every $\mu_t \geq 0$. The tax schedule therefore rules out equilibria with unemployment. At $z = D$, the tax is zero, and the initial steady state remains an equilibrium. Each household takes the tax rate as given when choosing its own borrowing.

Appendix D Numerical Details and Additional Results

D.1 Equilibrium Computation

We solve for laissez faire equilibria satisfying household and intermediary optimality, market clearing, the borrowing constraint, and the wage floor. The solution iterates on continuation exchange rates, with interpolation across states, and yields household lifetime utility U^{LF}.

For $\iota = 0$, we select the equilibrium with the largest debt among those with a nonbinding borrowing constraint. If no such equilibrium exists, we select the binding equilibrium with the largest debt. For $\iota = 1$, we select the binding equilibrium with the smallest debt, or the $\iota = 0$ outcome if no binding equilibrium exists. These rules and the sunspot probability are held fixed across policy experiments.

The calibration minimizes squared differences between simulated and targeted moments. The stationary laissez faire distribution supplies the initial state weights for the policy comparisons.

D.2 Policy Computation and Aggregation

We solve the temporary program by backward induction using the value functions in Section 5. The period-4 continuation is laissez faire at net debt $d_4 - a_4$. We then solve the settlement equilibrium and the period-2 equilibrium for each forward offer. If several hedge ratios support the same selected debt, we use the allocation with the lowest household continuation utility. The central bank chooses a forward rate or abstains before the sunspot is realized. The tax experiment uses the same timing, with laissez faire continuation from period 3. Policy rates are chosen from discrete candidate sets, and continuation values are interpolated across states and coverage.

All comparisons use the same laissez faire initial weights and physical transition probabilities. We average expected exchange rates across initial states before computing their percentage change relative to laissez faire. Volatility and consumption equivalents are computed within each initial state and then averaged. Cumulative crisis risk is the probability of at least one crisis in periods 3–5.

D.3 Additional Results

Across the full stationary distribution, including states without intervention, DNDFs lower the expected period-2 exchange rate by 1.14% and period-3 exchange rate volatility by 1.46 percentage points. Table A4 reports volatility and crisis probabilities at additional horizons.

TABLE A4: Additional Risk Measures in Intervention States (%)

	Laissez faire	DNDF	Capital control
Exchange rate volatility in period 2	2.05	2.24	1.95
Exchange rate volatility in period 4	7.66	9.44	4.85
Crisis probability in period 2	1.184	1.184	1.184
Crisis probability in period 5	0.653	0.724	0.468

Notes. Volatility is $100\,\mathrm{sd}_{2a}(\log e_t)$, computed within each initial state using physical probabilities and then averaged. A crisis has a positive borrowing constraint multiplier. Measures use common laissez faire weights over intervention states.

In the high-debt states in Table 5, DNDFs appreciate the period-2 exchange rate under normal expectations by about 71–87% relative to laissez faire. The rise in laissez faire debt/GDP across these states reflects both higher debt due and lower output.