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Understanding the Role of Expectations in Mexico

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Abstract

This paper estimates a hidden Markov model where inflation is determined by government deficits financed through money creation and/or by destabilizing expectations dynamics (expectations can potentially divorce inflation from fundamentals). The baseline model, proposed by Sargent et al. (2009), is used to analyze the interaction between fiscal deficits, inflation expectations, and inflation in Mexico. The model is able to distinguish between causes and remedies of hyperinflation, such as persistent or transitory shocks to seigniorage-financed fiscal deficits, de-anchoring of inflation expectations from fiscal fundamentals, and *cosmetic* (non-fundamental) monetary reforms. The behavior of monetized deficits provides an adequate account of high inflation episodes and stabilizations for the period 1969-1994. The paper then extends the model to analyze the possibility that fiscal policy can affect inflation expectations in a context of Central Bank independence, as is the case of Mexico after 1994. Evidence is found that the exchange rate and sovereign interest rate spreads influence the evolution of aggregate prices.

JEL: E31, E42, E52, E63.

Keywords: Inflation, Inflation expectations, Fiscal policy.

1 Introduction

As in other countries in Latin America during the second half of the twentieth century, Mexico suffered several episodes of annual inflation rates above 50 percent. These high inflation episodes were typically accompanied by elevated levels of public deficit financed with monetary expansions.[1] Until 1994, a regime of fiscal dominance prevailed, where the Central Bank adjusted its monetary policy to the financial requirements of the fiscal authority. Thereafter, the autonomy of Banco de México was established and inflation started a process of moderation.

To analyze the interaction between inflation, inflation expectations, and fiscal deficits in Mexico, we utilize the model developed by Sargent et al. (2009). This model has been used to infer the determinants of hyperinflations and stabilizations in different countries in Latin America (Argentina, Bolivia, Brazil, Chile, and Peru). It gives a central role to government deficits financed through money creation, but also to destabilizing expectations that can, under certain conditions, divorce inflation from fundamentals. The baseline framework consists of a non-linear hidden Markov model with the following key components: i) a standard demand function for real balances, ii) an adaptive scheme for the expected rate of inflation,[2] iii) a government budget constraint that relates fiscal deficits to monetary supply, and iv) a stochastic fiscal deficit that follows a hidden Markov process. With these components, the model is able to distinguish between the causes and remedies of hyperinflations, such as persistent or transitory shocks to seigniorage-financed fiscal deficits, de-anchoring of inflation expectations from fiscal fundamentals, and *cosmetic* (non-fundamental) monetary reforms. Sargent et al. (2009) conclude that the behavior of monetized deficits determined most hyperinflations and stabilizations for the set of countries they studied.

We first use the baseline model to account for the evolution of inflation in Mexico between 1969 and 2016. The methodology uses a series for inflation, interpreting the density of the inflation series as a likelihood function in order to estimate the history of fiscal deficits and the process of the formation of inflation expectations that better account for the evolution of inflation. This approach is convenient given numerous methodological modifications in the construction of public accounts, the sometimes less-than-ideal transparency in historical series, and the fluctuations in the perception of economic agents of what constitutes fiscal responsibility for the government (e.g., bailouts of the financial system or sub-national governments). These problems plague historical accounts of events in developing economies. The estimated sequence of fiscal deficits is then compared to available data for government deficits and a historical narrative of the events associated with episodes of high inflation and stabilizations. In line with the results for other countries, the model suggests that the evolution of fiscal deficits is central in explaining the behavior of inflation

1 Fischer et al. (2002), Catao and Terrones (2005), and Lin and Chu (2013), among others, document international evidence regarding the relationship between inflation rates, fiscal deficits, and money supply. Rogers and Wang (1994) estimate that between 1977 and 1990, fiscal and monetary shocks accounted for 60 percent of the variance of inflation in Mexico.

2 Agents have adaptive expectations or backward-looking expectations when these are formed by extrapolating past values of the variable being predicted.

in Mexico. Furthermore, it provides a description of the formation of inflation expectations. For example, the parameters of the model suggest that inflation must be high for several consecutive periods in order to de-anchor inflation expectations and generate an inflation spiral.

For the period of decreasing inflation that started in the second half of the 1990s, the baseline model suggests that the level of fiscal deficits financed through monetary expansion is modest. This interpretation, however, is not fully satisfactory, as the Central Bank became independent in 1994. Thus, a theory that *contemporaneously* links inflation to fiscal deficits through the monetary channel seems lacking if we aim to understand inflation after 1994. This motivates the following question: can we find evidence that fiscal policy affects inflation and inflation expectations even in the context of Central Bank independence?

A strand of the macroeconomic literature proposes that fiscal policy is relevant to achieving price stability even in an environment where monetary policy is conducted by an independent Central Bank.[3] We extend the baseline model along several dimensions with the objective of documenting evidence, perhaps indirect, or rebutting the possibility that fiscal policy is relevant in determining inflation and inflation expectations in a context of Central Bank independence. A variable of interest we consider is the spread in the sovereign interest rate EMBI. This variable, which can be considered *forward-looking*, reflects the fiscal situation of the government. To the extent that economic agents perceive potential risks in terms of the ability of the government to make debt payments, it may also affect the credibility of the Central Bank. The perception of this type of risk is incorporated into the prices of sovereign debt. The state of public finances is often considered to affect the exchange rate; this is the second variable we assess in the model. The results indicate that both variables are relevant in determining inflation expectations and inflation.[4]

We proceed as follows: Section 2 presents the baseline model and describes the mechanisms that drive the behavior of the different variables. Section 3 presents the main results for the baseline model: i) the parameter values of the model and their implications in terms of the behavior of the main variables, ii) a comparison of the inflation series generated by the model and those observed in the data, with a historical account of the events associated with the different high-inflation and stabilization episodes, and iii) a comparison of the series for fiscal deficits generated by the model with the historical series. Section 4 presents the extensions of the

3 There exists a vast literature studying the relevance of fiscal policy and its interaction with monetary policy for the determination of inflation; a seminal paper is Sargent and Wallace (1981). Though we do not attempt to provide an exhaustive set of references, some additional examples are provided by Sims (2016), Leeper (1991), Davig et al. (2011), Sargent and Zeira (2011), Woodford (2001), and Bianchi and Ilut (2017). For an introductory treatment of *the fiscal theory of the price level*, see Christiano and Fitzgerald (2000). Central Banks frequently express concern related to how fiscal imbalances may affect the effectiveness of monetary policy (e.g., Carstens and Jácome (2005) and Ramos-Francia and Torres-Garcia (2005)).

4 There are different mechanisms through which these variables could potentially be relevant; we explore the impact through expectations and the demand for real money balances. We discuss the evidence of the extent to which these variables are influenced by international and exogenous factors, with a focus on the case of Mexico, such as prices of commodities in global markets.

model and the main results. Section 5 provides our concluding remarks.

2 The Baseline Model

The baseline model is the one featured in Sargent et al. (2009), constructed to study the relationship between inflation, fiscal deficits, and inflation expectations. An advantage of this model is its simple structure, which allows for the estimation of its parameters using only the historical series of one of the main variables, in our case the monthly inflation series (the estimation algorithm is described briefly in the next section and in the Appendix). With these parameters, the model accounts for an observed sequence of inflation as a result of fiscal deficits and a particular process for the formation of inflation expectations. The framework consists of following main components: a money demand function, the budget constraint of the government, a process that models the formation of expectations, and the (exogenous and stochastic) evolution of deficits. We now describe each of these components.

2.1 The Money Demand and the Government Budget Constraint

A standard money demand equation (e.g., Cagan (1956)) establishes a relationship between the nominal balances as a percentage of output M_t at time t, the price level P_t at time t, and the expectations of agents of the price level P^e_{t+1} for period $t+1$:[5]

$$\frac{M_t}{P_t} = \frac{1}{\gamma} - \frac{\lambda}{\gamma}\frac{P^e_{t+1}}{P_t}, \tag{1}$$

where $\lambda \in (0,1)$ represents the weight that the expected price level P^e_{t+1} has on the current price level P_t, and $\gamma > 0$ is the weight that the nominal balances relative to output have on the price level at time t.[6] Thus, if the public expects a higher price level in $t+1$, their real balances demand M_t/P_t will fall.

The next equation represents the budget constraint of the government, where d_t (a stochastic variable) is the part of the real deficit of the government that is monetized (net of debt emissions, so it must be covered by printing money). Thus, the growth of nominal balances per unit of output is determined according to the following equation:

$$M_t = \theta\, M_{t-1} + d_t\, P_t, \tag{2}$$

where parameter $\theta \in (0,1)$ adjusts for growth in real output and taxes on cash balances.[7] This equation implies that larger fiscal deficits are associated with increases

5 In a seminal paper, Cagan (1956) specifies a demand for real balances and backward-looking expectations to explain several European hyperinflation episodes.

6 Equation (1) can be written as $P_t = \gamma M_t + \lambda P^e_{t+1}$. Hence, $\{\lambda, \gamma\}$ represent the weights that P^e_{t+1} and M_t have on P_t, respectively.

7 Parameter θ is related to output growth in the model. Let $M_t = \frac{\hat{M}_t}{Y_t}$ where $\hat{M}_t$ are the nominal balances at time t and Y_t is output. If D_t represents the level of real fiscal deficit at time t, then the government budget constraint is $\hat{M}_t = \hat{M}_{t-1} + P_t D_t$. Dividing this equation by Y_t then: $M_t = \frac{Y_{t-1}}{Y_t} M_{t-1} + P_t d_t$. Therefore, θ can be interpreted as the inverse of the output growth factor. Consequently, this model is assuming a constant output growth rate. Quantitatively, this parameter is not relevant for our results.

in the level of nominal balances as a percentage of GDP.[8]

We let $\beta_t = P^e_{t+1}/P_t$ denote the gross expected inflation rate. Using (1) and (2) it can be shown that the gross inflation rate at time t is:

$$\pi_t = \frac{P_t}{P_{t-1}} = \frac{\theta(1-\lambda\beta_{t-1})}{1-\lambda\beta_t-\gamma d_t}. \tag{3}$$

This equation suggests that inflation is a function of two variables: the expected gross inflation rate and the real fiscal deficit. According to (3), if the expected gross inflation rate β_t or fiscal deficit d_t rise, current inflation π_t will also increase.[9] It is worth mentioning that equation (3) does not depend on the particular process through which inflation expectations are formed, or the stochastic process assumed for fiscal deficits. Nevertheless, these assumptions are crucial to determine a sequence of inflation rates $\{\pi_t, \pi_{t+1}, \ldots\}$ according to the model. The next two sections will explain the specification for the evolution of expectations and the dynamics followed by the real fiscal deficit.

2.2 Inflation Expectations

The baseline specification follows, for example, Marcet and Nicolini (2003), assuming that the public updates their beliefs on future inflation β_t using adaptive expectations. According to Sargent and Wallace (1973), agents have adaptive expectations when they take into account past information and extrapolate from it to form their expectations. Specifically in this model, the gross expected inflation rate is a weighted average between the gross inflation rate and the gross expected inflation lagged one period:

$$\beta_{t+1} = (1-\nu)\beta_t + \nu\pi_t, \tag{4}$$

where $0 < \nu < 1$ is the weight that expectations give to past observed inflation. In related literature, this particular type of adaptive expectations is known as constant-gain expectations, given the constant weight in the process that determines the formation of expectations.[10]

Assuming constant-gain expectations (CGE) is key in determining the dynamics of the model. Panel **(a)** of Figure I shows the change in gross inflation $\pi_{t+1} - \pi_t$ as a function of expectations β_t, with a constant real fiscal deficit. As shown in the figure, there are two values of β that imply a constant inflation equilibrium: β_1 and β_2. In the adaptive expectations literature, β_1 and β_2 are known as *self-confirming*

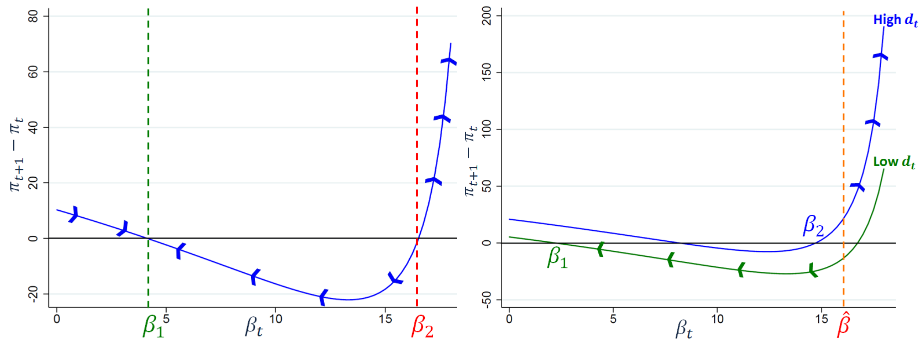
8 We are defining the fiscal deficit as $d_t = g_t - \tau_t + (1+r_t)b_t - b_{t+1}$, where g_t and τ_t represent government expenditures and revenues relative to output, b_t is the level of sovereign debt relative to output and r_t is the interest rate on sovereign debt.

9 This is obtained with $\lambda \in (0,1)$, $\theta \in (0,1)$, and $\gamma > 0$.

10 For example, Branch (2004) develops a micro-founded model where agents optimally choose not to update their beliefs according to a rational expectations algorithm because the information it requires is too costly (rational expectations algorithms usually require a large amount of information). In the type of models we are considering, adaptive expectations or other deviations from rational expectations, can be necessary to generate hyperinflation episodes (e.g., Sallum et al. (2005)). See Sargent et al. (2009) for a list of references in a growing literature using calibration or econometric techniques to compare time-series data with models in which agents use this type of algorithm to form their beliefs.

equilibria. As implied by the figure, β_1 is a locally stable equilibrium, thus, if the beliefs of the public regarding future inflation are not sufficiently high then $\pi_{t+1} - \pi_t$ will converge to zero and β_{t+1} to β_1. Additionally, equation (4) implies that π_t will also converge to β_1. However, if $\beta_t > \beta_2$, then $\pi_{t+1} - \pi_t$ will increase, with unbounded dynamics. Therefore, $\beta_t > \beta_2$ implies that the model will eventually generate a hyperinflation episode. This phenomenon is called **escape dynamics** by Sargent et al. (2009).[11]

Figure I: Dynamics Induced by Adaptive Expectations



(a) Inflation and Expectations (b) Fiscal Deficit and Expectations

Notes: These figures consider $\beta_{t-1} = 1.02$ and the estimated parameters shown in Table I.

Panel **(b)** of Figure I presents another result of CGE: assuming β_t induces escape dynamics, a hyperinflation episode can be prevented if the deficit is reduced. This panel shows two dynamic paths for $\pi_{t+1} - \pi_t$ as a function of β_t. The only difference between these paths is the level of fiscal deficit. The dynamics shown in blue correspond to a high fiscal deficit, while the dynamics in green correspond to a low fiscal deficit. Assuming a high deficit and $\beta_t = \hat{\beta}$, if the deficit is not reduced then it will provoke an escape dynamics of inflation and expectations as shown with blue arrows in Panel **(b)** of Figure I. However, if the government reduces its fiscal deficit to a sufficiently low level then, even when $\beta_t = \hat{\beta}$, it will be able to prevent an escape dynamics. Furthermore, $\pi_{t+1} - \pi_t$ will converge to a low and stable inflation equilibrium as shown by the green arrows in the figure.

Finally, CGE implies a non-trivial computational advantage: given the complexity of the function that will be used to estimate all the parameters involved in the model, assuming this type of expectations allows us to reduce the computational burden.[12] We discuss the implications of using rational expectations in the Appendix.

2.3 The Process for Fiscal Deficits

The last key variable that determines inflation rates is the level of real fiscal deficit

11 Williams (2016) characterizes how adaptive expectations can lead to escape dynamics and explains how the likelihood, frequency and direction of the variables during an escape dynamics can be characterized by a deterministic control problem.

12 The next section explains some of the details involved in estimating the parameters of model.

relative to output d_t. The fact that d_t is assumed to be a random variable is motivated by, among other factors according to our interpretation, exogenous conditions in global financial markets, the international price of commodities that are crucial in determining the fiscal situation of many governments in developing economies, and political processes. With these considerations, in an admittedly reduced form, it is assumed that d_t is a random variable with the following conditional distribution:

$$log(d_t|\bar{d}_t, v_t) \sim N(log(\bar{d}_t), v_t). \tag{5}$$

Thus, d_t is a random variable with a log-normal distribution that has a median of $\bar{d}_t$ and a variance parameter v_t. A restriction of assuming a log-normal distribution for fiscal deficits relative to output is that d_t cannot be negative (a fiscal surplus is not feasible). Sargent et al. (2009) explain that even when they allow the distribution of d_t to have negative values, there is not a significant improvement in the fit of the model. Furthermore, a log-normal distribution captures the skewness of inflation shown in the data. In the case of Mexico, we will see that three values for $\bar{d}_t$ are sufficient to adequately capture the evolution of deficits during the period we analyze.

Each period, $\bar{d}_t$ is determined by a discrete Markov process with D possible states.[13] In the same manner, v_t follows another Markov process with V states that is independent of the process that determines $\bar{d}_t$. In related literature, the stochastic process followed by d_t is called a **Hidden Markov Process**.[14] Each Markov process involved in the model is related to a matrix where the elements represent the transition probabilities from one state of the process to another. We let $Q_d \in \mathbb{R}^{D\times D}, Q_v \in \mathbb{R}^{V\times V}$ be the transition matrix associated to the $\{\bar{d}_t, v_t\}$ processes, respectively.[15] Thus, the model provides sufficient flexibility to capture different regimes in terms of levels and volatilities of inflation.

Another important property of the model is that it generates a non-linear relationship between inflation, its expectations, and fiscal deficits. The impact that current inflationary expectations β_t have on inflation π_t and future expectations β_{t+1} is a function of the hidden Markov state that governs the median fiscal deficit $\bar{d}_t$. An example of the non-linearity generated by the hidden Markov process of the model can be seen in Panels **(a)** and **(b)** of Figure II. Panel **(a)** shows that, for the same level of β_t, the effect of the fiscal deficit on inflation is magnified as the median level of fiscal deficit $\bar{d}_t$ rises (this figure considers $\bar{d}_1 > \bar{d}_2 > \bar{d}_3$). Panel **(b)** displays a similar effect of fiscal deficit on the evolution of inflation expectations. This

13 A stochastic process x_t is said to be a discrete Markov process if x_t takes values in a set I with $|I| \in \mathbb{N}$ and for all $t = 1, 2, \ldots$ the Markov property is satisfied: $P[x_{t+1} = i|x_0, x_1, \ldots, x_t] = P[x_{t+1} = i|x_t]$. This property states that past realizations of the process $\{x_0, x_1, \ldots, x_{t-1}\}$ do not affect future values, only the present state x_t affects x_{t+1}.

14 Formally, a hidden Markov process is a pair $\{x_t, y_t\}$ such that x_t is a (standard) Markov process and there exists a function f such that for all $t = 1, 2, \ldots$, $y_t = f(x_t)$ and:

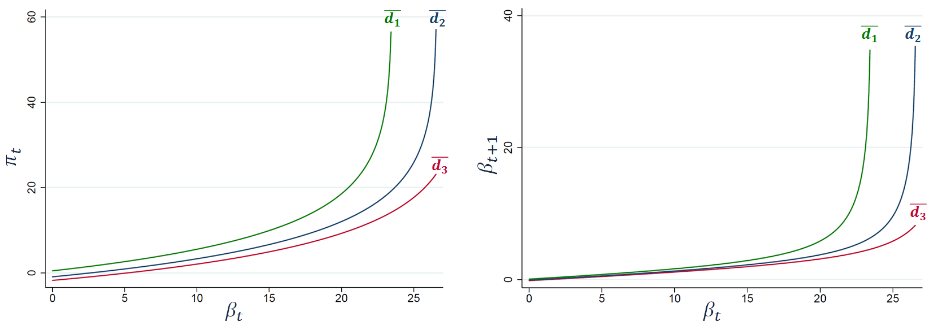
$$P[y_{t+1} = y|x_0, x_1, \ldots, x_{t+1}, y_0, y_1, \ldots, y_t] = P[y_{t+1} = y|x_{t+1}].$$

In processes of this type, y_t is known as the observable part of the process and x_t is the hidden component. In the model presented in this section, y_t is the real fiscal deficit relative to output while x_t is a vector that contains the median $\bar{d}_t$ and variance v_t of fiscal deficit at each t.

15 This means, in the case of $\bar{d}_t$, Q_d in its $(i, j)-$component contains the probability of being in a state j in $t + 1$ conditional on $d_t = i$: $Q_d(i, j) = P[\bar{d}_{t+1} = j|\bar{d}_t = i]$.

non-linearity between the inflation rate, its expectations, and fiscal deficits in the model is consistent with empirical studies. For example, Catao and Terrones (2005) and Lin and Chu (2013) provide evidence, utilizing data for more than 100 countries, that fiscal deficits have a strong and weak impact on the inflation rate in high and low inflation episodes, respectively. Thus, the data and the model suggest that there is a non-linear impact of fiscal deficits on inflation and expectations of inflation.

Figure II: Non-Linear Effect of Fiscal Deficits



(a) Effect on Inflation

(b) Effect on Expectations

Notes: This figure considers $\beta_{t-1} = 1.02$ and the estimated parameters as described in the next section.

2.4 Model Restrictions on Expectations

Equation (3) implies that inflation in the model is well defined only if at each t: $1 - \lambda\beta_{t-1} > 0$ and $1 - \lambda\beta_t - \gamma d_t > 0$ (otherwise the real balances demand could become negative). However, there is no restriction within the model preventing these constraints from being violated. Furthermore, (3) implies that the gross inflation rate is not bounded.[16] Given the numerical problems that this can generate when estimating the parameters, it is assumed that there exists a constant $\delta > 0$ such that $\pi_t < \delta$ for every t.

The two restrictions that need to be considered such that π_t is well defined and bounded are:

$$1 - \lambda\beta_{t-1} > 0 \quad \text{and} \quad \delta(1 - \lambda\beta_t - \gamma d_t) > \theta(1 - \lambda\beta_{t-1}). \tag{6}$$

If any of these constraints is violated, then it is assumed that the gross inflation rate is not determined following (3). Instead, π_t will be determined randomly according to the following log-normal distribution:

$$log(\pi_t) \sim N(log(\bar{\pi}_t(d_t)), v_\pi), \tag{7}$$

where $\bar{\pi}_t(d_t)$ is the inflation equilibrium determined by (3) in the model without uncertainty and conditional to a certain fiscal deficit d_t,[17] whereas v_π repre-

16 If $1 - \lambda\beta_t - \gamma d_t \to 0$, then $\pi_t \to \infty$.

17 Certainty in the model implies $\pi_t = \beta_t$. In equilibrium, $\pi_t = \pi_{t-1}$. Using (3) it can be shown that: $\bar{\pi}_t(d_t) = (1 + \theta\lambda - d_t - \sqrt{(1 + \theta\lambda - d_t)^2 - 4\theta\lambda})/2\lambda$.

sents the variance of inflation when it is determined following (7). Additionally, if $\delta(1 - \lambda\beta_t - \gamma d_t) \leq \theta(1 - \lambda\beta_{t-1})$, Sargent et al. (2009) suggest resetting expected inflation to $\beta_{t+1} = \pi_t$, otherwise the dynamics between β_{t+1} and inflation will provoke $\pi_{t+1} \geq \delta$ and eventually $\beta, \pi \to \infty$.

Whenever the current hidden Markov state $\{\bar{d}_t, v_t\}$ provokes dynamics that will eventually make $\{\pi, \beta\}$ violate (6) or that will generate an escape dynamics, the government can implement a ***reform*** to prevent this from happening. Sargent et al. (2009) define two types of reforms: a reform is said to be ***cosmetic*** if the government is able to (temporarily) control inflation but the median level of fiscal deficit is not altered. Following Panel **(a)** of Figure I, a cosmetic reform can fail if the expected inflation rate associated with inflation β_{t+1} is such that $\beta_{t+1} > \beta_2$. However, a cosmetic reform can be successful if $\beta_{t+1} \leq \beta_2$.[18] A ***structural reform***, on the other hand, occurs when the government is able to control the inflation rate by reducing the median level of fiscal deficit, $\bar{d}_t$. Panel **(b)** of Figure I is an example of a structural reform where the government succeeded in controlling an escape dynamics.

An important contribution of the model is its ability to identify whether a reform is cosmetic or structural. Previous literature had only studied structural reforms, although the notion of a cosmetic reform was part of academic and economic policy discussions. The inclusion of cosmetic reforms in the model represents a reduced form approach to consider different episodes in Latin America, when governments attempted to control inflation without tackling fiscal deficits. Discussions of economic events often point to the role of the exchange rate, which is not explicitly included in the baseline model, and we explore below through different extensions of the baseline model.

3 Baseline Model Results

In this section, we present the main results of the baseline model. We present the fit of the model for real fiscal deficits, inflation, and its expectations between 1969 and 2016. Then, as a validation procedure, we compare these model-fitted series with data available for different variables.

3.1 Baseline Model Estimation

Heuristically, the estimated parameters are obtained as the vector of values that maximize the likelihood function, which consists of the marginal density of the sequence of inflation.[19] The inflation data corresponds to the *Índice Nacional de Precios al Consumidor* (INPC) between 1969 and 2016, at a monthly frequency. The INPC is the Consumer Price Index (CPI) computed by the National Institute of Statistics and Geography, *Instituto Nacional de Estadística y Geografía* (INEGI) since 2011,

18 Sargent et al. (2009) argue that in Peru a cosmetic reform was enough to control the inflationary crisis this country experienced in 1985.

19 In the Appendix we provide further details regarding the estimation of the model. Ramirez de Aguilar (2017) describes the computational procedure.

and by Banco de México before that year.

We consider a monthly frequency for the model estimation, consistent with the data. Before estimating the parameters, one must choose the number of states of nature for $\{\bar{d}, v\}$: denoted D and V, respectively. As D or V become larger, the fit of the model in terms of approximating the data tends to improve at the expense of increasing the computational burden. Sargent et al. (2009) estimate two models for each country they study: a model with $D = 3, V = 2$ and a model with $D = 2, V = 3$. Then, using the Schwarz information criterion (SIC), we select the model that provides a better fit to the data.[20] Table I shows the estimation results for a model with three possible states for $\bar{d}$ ($D = 3$) and two states for v ($V = 2$). We choose this model because, after estimating the two models with data for Mexico, the SIC suggests that $D = 3$, $V = 2$ provides a better approximation to the data.

Table I: Parameter Estimation

parameter	estimation	description
λ	0.7556 (0.0022)	weight of expectations on the price level
ν	0.1147 (0.0081)	weight of past inflation on expectations
$\bar{d}_1$	0.0075 (0.0001)	monthly *high* median level of fiscal deficits
$\bar{d}_2$	0.0039 (0.0004)	monthly *moderate* median level of fiscal deficits
$\bar{d}_3$	0.0023 (0.0002)	monthly *low* median level of fiscal deficits
v_1	0.0671 (0.0087)	high variance of monthly fiscal deficits
v_2	0.0295 (0.0012)	low variance of monthly fiscal deficits
v_π	0.0753 (0.0010)	variance of inflation when it is determined randomly
p^d_{11}	0.9731 (0.0361)	probability of $\bar{d}_{t+1} = \bar{d}_1$ conditional on $\bar{d}_t = \bar{d}_1$
p^d_{22}	0.9787 (0.0390)	probability of $\bar{d}_{t+1} = \bar{d}_2$ conditional on $\bar{d}_t = \bar{d}_2$
p^d_{33}	0.9924 (0.0056)	probability of $\bar{d}_{t+1} = \bar{d}_3$ conditional on $\bar{d}_t = \bar{d}_3$
p^v_{11}	0.7493 (0.1072)	probability of $v_{t+1} = v_1$ conditional on $v_t = v_1$
p^v_{22}	0.7789 (0.0879)	probability of $v_{t+1} = v_2$ conditional on $v_t = v_2$

Notes: The numbers shown in parentheses represent the standard error of each parameter, computed using the Hessian matrix of the maximum likelihood problem (see MacDonald and Zuccini (2009)).

The estimated parameters suggest interesting facts about the price formation process in Mexico: $\lambda = 0.7556$ implies that the price level reflects agents' expectations on the future price level. Hence, if inflation expectations are volatile, then the observed inflation will also have a high variance. This result implies that a necessary condition to have stable inflation is to anchor expectations. Mexico's λ is similar to the estimation by Sargent et al. (2009) for Argentina ($\lambda = 0.730$) and Peru ($\lambda = 0.740$).

The estimated value of $\nu = 0.1147$ for Mexico implies that to anchor expectations, observed inflation must remain stable for several months.[21] On the other hand, this

20 The SIC is a Bayesian selection criterion between two models, A and B. Let L_x, P_x, n_x be the log-likelihood, the number of parameters, and the sample size in model $x \in \{A, B\}$, respectively. Then, the Schwarz criterion for model x is computed as $SIC_x = log(n_x)P_x - 2L_x$. If $SIC_A < SIC_B$, then model A is preferred.

21 The estimation of $\nu = 0.1147$ implies that the weight agents give to their past expectations is

also implies that the expected inflation rate de-anchors only if the observed inflation is high for an extended period. Sargent et al. (2009)'s estimations for Argentina ($\nu = 0.023$), Chile ($\nu = 0.025$), and Peru ($\nu = 0.069$) indicate that, in these countries, observed inflation has a relatively limited effect on inflation expectations, while the estimates for Bolivia ($\nu = 0.232$) and Brazil ($\nu = 0.189$), suggest that observed inflation has a stronger impact on expectations.

Regarding fiscal deficits, according to the estimation, when the government generates a high fiscal deficit for one year ($\bar{d} = \bar{d}_1$ for 12 consecutive months), fiscal deficit represents approximately 9.12% of GDP. If the government generates a moderate deficit for one year, this will amount to approximately 4.76% of GDP. Finally, if fiscal deficits are low for one year, then it represents 2.78% of the GDP. These levels of deficit are associated, in steady state, with average annual inflation rates of 69.41%, 17.53% and 3.54%, respectively. As will be shown, these estimates are consistent with fiscal deficit data between 1977 and 2016.

3.2 Fiscal Deficits, Inflation, and Expectations

Once the parameters are estimated, fiscal deficits relative to output can be computed in each period exploiting the assumptions made for $\{d_t|\bar{d}_t, v_t\}$ and considering that $\{\bar{d}_t, v_t\}$ follow a discrete Markov process. We estimate the conditional density of fiscal deficits given the sequence of inflation observed in the data π^T and the parameter estimation, $p(d_t|\pi^T, \hat{\phi})$. Then, we use the median of each density to construct a sequence $\{d_t\}_{t=1}^T$ that is used to compute $\{\pi_t, \beta_t\}_{t=1}^T$ according to the model. Finally, we compare the model implied sequence of inflation $\{\pi_t\}_{t=1}^T$ with the empirical series. Figure III presents the model simulation for fiscal deficits, inflation expectations, observed inflation, and the probability of a regime change in $\bar{d}$.

- Between 1969 and 1972, marked as Region **(1)** in Figure III, a low rate of inflation is associated with the lowest hidden state of median deficit $\bar{d}_3$. This is consistent with the economic history of Mexico; during the decade of the 1960s, the inflation rate in Mexico achieved its lowest value during the second half of the twentieth century: an average of 2.8%, which is replicated by the model.[22]

- Between 1973 and 1982, marked as Region **(2)** of the figure, the model suggests that fiscal deficits increased from a low to a moderate median level, accompanied by an increase of the inflation rate. Since this level of deficit remained constant for several years, inflation expectations de-anchored. Consequently, the observed inflation rate also presented an increase between 1973-1982. At the end of 1971, a global recession reduced international credit. Fearing a

0.8853. Hence, if inflation is stable for only one month, this will not be enough to reduce β because past beliefs have more weight on expectations. Only if the inflation rate is stable for several consecutive months will β also become stable.

22 In this section we draw from Cardenas (2015), who provides an exhaustive narrative of the economic history of Mexico during the period of our analysis. Historical series for output and the inflation rate data presented in this section were obtained in the *Historical Statistics of Mexico* published by INEGI.

period of stagnation, the government responded by increasing public expenditures financed with monetary emission, foreign credit, and reserves of private financial institutions at the Central Bank. The fiscal deficit relative to output increased from 2.5% of GDP in 1971 to 4.9% in 1972, while the monetary base grew 14.8% during 1972, the rate of inflation registered an average of 14% during 1973-1976. Meanwhile, government expenditures increased from 30.9% relative to output to 40.6% in 1981; the fiscal deficit relative to output rose from 6.7% in 1977 to 14.1% in 1982.

- In 1981, the world economy was going through another recession that once again reduced international credit. In Mexico, there was not a significant reduction in expenditures and by 1982 the lack of foreign credit led the government to finance most of its expenditures with monetary emission: between 1981 and 1983, the monetary base was growing at an average rate of approximately 90% and the inflation rate was 63.1% on average. During 1983, the model generates an inflation rate above 80% as a result of an increase in fiscal deficits, which reached their highest median level. During 1983-1986, the government raised taxes and renegotiated its foreign debt. However, there was not a significant adjustment of expenditures; by 1986 the fiscal deficit reached the same level it registered in 1982, equal to 14.1% of GDP. In 1985 world oil prices fell and by 1986 the price of the Mexican oil mix suffered a drop of 65%, generating a loss equivalent to 6.5% of GDP and a reduction of 26% in federal income. By 1987, the annual inflation rate was 159%.[23]

- Region (3) of Figure III presents evidence of a **cosmetic reform**, to control inflation: during 1984 the government was able to reduce inflation from 85% to 56%, according to the model, due to a temporal reduction of its fiscal deficit. However, as shown by Panels **(a)** and **(d)** the median fiscal deficit between 1985-1987 remained at the highest possible (estimated) value. As a consequence, inflation began to grow once again in 1985.

- After the 1987 crisis, in 1988 the Mexican government reached an agreement with representatives of the private sector called the Economic Solidarity Plan (in Spanish: *Pacto de Solidaridad Económica*) in which the government committed to reducing expenditures and inflation. The fiscal deficit came to historical lows and even achieved surpluses, and the government was able to restructure its debt. By 1989 the annual inflation rate was lowered to 20.3%. The model is consistent with this episode of economic history in Mexico; through the lens of the model, the government conducted a **structural reform**: between 1988 and 1993 (Region **(4)** of the Figure), fiscal deficits were reduced from the highest possible median $\bar{d}_1$ to a moderate level $\bar{d}_2$ in 1989 and then in 1993 to a lower median $\bar{d}_1$. This reduction of the fiscal deficit had an immediate impact on inflation and its expectations.

- Several factors induced another crisis at the end of 1994 and during 1995. The re-privatization of the banks was financed with foreign debt, which left the financial sector exposed to sudden exchange rate movements and increments

23 Cardenas (2015) argues that the crisis presented during 1987 is a direct consequence of the unwillingness of the government to reduce its deficit during 1982-1987.

in interest rates. Additionally, the government issued bonds that were paid in pesos but with dollar nominal values (the Tesobonos), which required a stable exchange rate in order to keep this debt sustainable. However, political events led to a significant depreciation of the domestic currency in 1994 accompanied by capital outflows (Calvo and Mendoza (1996), Cole and Kehoe (1996) analyze these events). The government faced a debt crisis, the private financial sector found itself in bankruptcy, and the inflation rate reached 51% in 1995. The government negotiated loans with the International Monetary Fund (IMF) and with the United States in order to finance its debt.

- The model attributes, in Region **(5)**, the escalation in inflation during 1995 to an increase in fiscal deficit between 1994 and 1995. However, this escalation was a consequence, to a significant extent, of the nominal exchange rate depreciation at the end of 1994 and the collapse of the financial sector in 1995. In this case, there is a discrepancy between the in-sample predictions of the model concerning fiscal deficit and what is observed in the data. This discrepancy between the model and the data motivates the introduction of the nominal exchange rate in the model. It will be shown that by introducing this variable we can better account for the behavior of inflation during 1995 and in general.

- After a constitutional reform in 1993, Banco de México became independent in 1994. The reform established as its primary mandate to preserve the purchasing power of the national currency.[24] The average annual inflation rate fell from 10.95% between 1996-2002 to 3.98% between 2003-2016, achieving historical minimums during 2015 and 2016.[25] Meanwhile, fiscal deficits remained relatively low and stable during 1997-2016.[26]

- During the last sub-period (Region **(6)** of Figure III), the model predicts that fiscal deficits were at the lowest median and variance hidden states. The model also shows that the expected inflation rate has fluctuated within the range of the target of Banco de México: an inflation rate of 3% that can vary between 2% and 4%. The model proposes that a necessary condition to anchor inflation and its expectations is a low monetization of fiscal deficit. The only year in which the fiscal deficit had a slight probability of being at a higher median state was in 2009, in the course of the global financial crisis. However, since the inflation rate remained low after 2009, the baseline model predicts that Mexico has remained in a low fiscal deficit regime.

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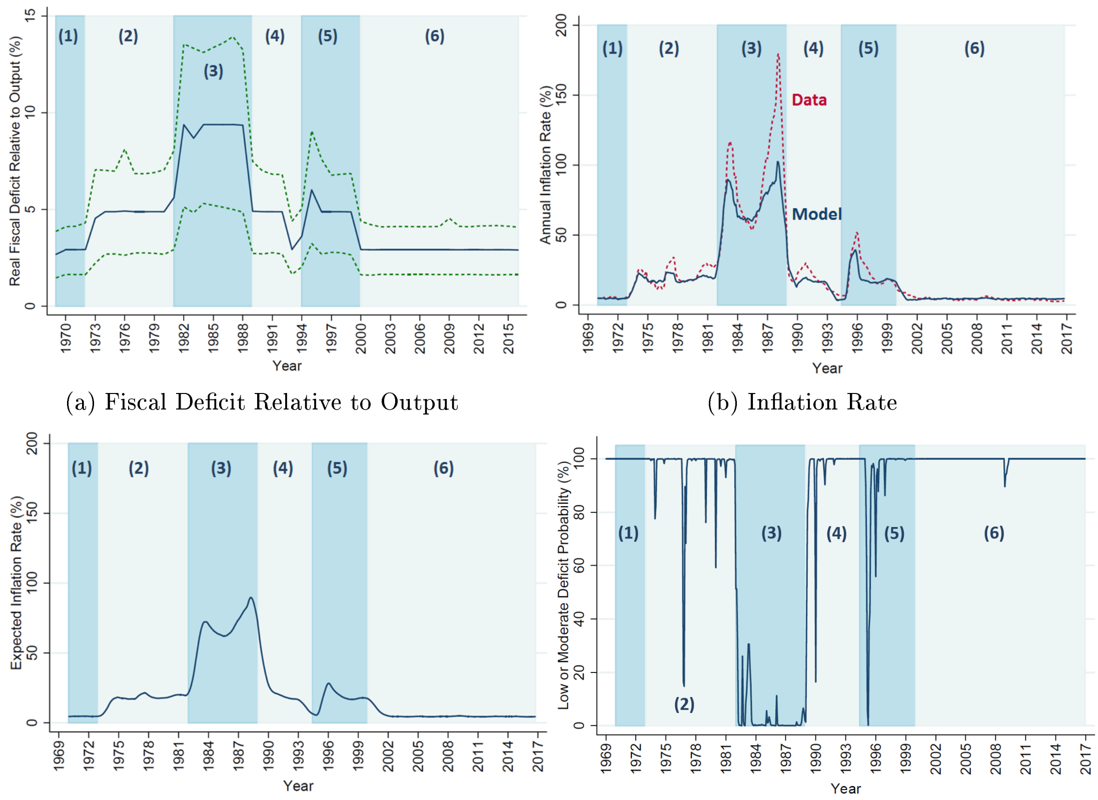
24 Some of the policies adopted by the Central Bank after 1994 were: i) restoration of the level of international reserves to gain credibility, ii) the use of an objective of cumulative current account balances that private banks held at the Central Bank as the primary monetary policy instrument, iii) adoption of an inflation-targeting policy, and iv) to improve transparency, the Central Bank began to publish reports communicating monetary policy decisions as well as quarterly reports on the economy. For a more detailed description of these policies see Ramos-Francia and Torres-Garcia (2005).

25 Furthermore, as documented by Chiquiar et al. (2010), the inflation rate after 2000-2001 became a stationary process and initiated its convergence towards the inflation target.

26 In 2008 there was a methodological modification in BPT that made it a wider measure of fiscal deficits: after 2008 the BPT considers part of the investments made by two important state-owned firms (*PEMEX* and *CFE*) that before were considered as long-term debt (investments of this type are called *PIDIREGAS*).

Figure III: Dynamics of the Model



(a) Fiscal Deficit Relative to Output

(b) Inflation Rate

(c) Expected Inflation Rate

(d) Probability of a Low Inflation Regime

Source: INEGI and model results.

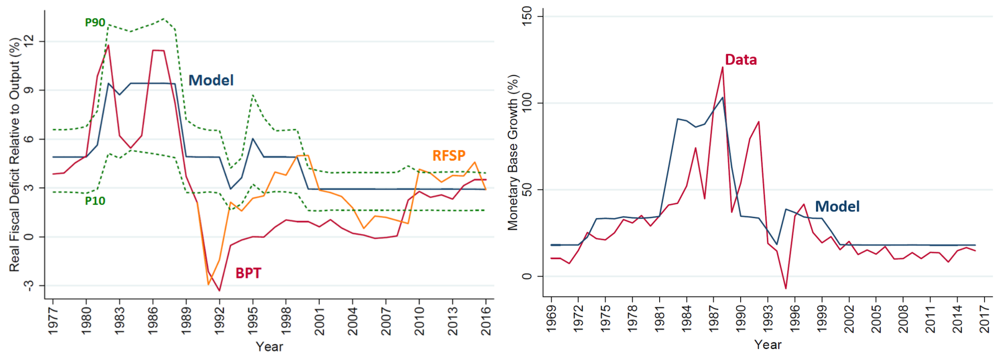
Notes: Panel **(a)** plots the median real fiscal deficit relative to output together with the 10^{th} and 90^{th} percentile of the annual deficit distribution. Panel **(b)** shows the annual inflation rate predicted by the model given the real fiscal deficit, and the data. Panel **(c)** shows the expected inflation rate according to the CGE algorithm (4). Panel **(d)** plots $P[\bar{d}_t = \bar{d}_2|\pi^t, \hat{\phi}] + P[\bar{d}_t = \bar{d}_3|\pi^t, \hat{\phi}]$ where $\bar{d}_2$ and $\bar{d}_3$ are the moderate and low levels of mean fiscal deficit.

Considering the inflation history previously described, we observe that the model predicts a deficit distribution with an elevated mean and variance during those years in which the inflation rate was elevated, as in 1987 (a year characterized by the highest inflation rate presented in Mexico during the second half of the twentieth century). In those years in which the inflation rate was moderately high, as in 1975, the model predicts a fiscal deficit with a moderate mean and lower variance than in 1987. Finally, in those years where the inflation rate is low, the fiscal deficit density is characterized by a low mean and variance.

3.3 Fiscal Deficits: Data and Model Simulation

There are available two official measures of fiscal deficits: *Balance Público Tradicional* (BPT) and *Requerimientos Financieros del Sector Público* (RFSP). The BPT, computed since 1977, represents the difference between current and capital expenditures with total revenue of almost all the public sector.[27] Since 1990 the Mexican Ministry of Finance, *Secretaría de Hacienda y Crédito Público* (SHCP), computes the RFSP which consider all the financial requirements that the government uses for its public policy at a federal level. This is a broader measure of fiscal deficit since it includes the BPT in addition to all revenues and expenditures of the public financial sector that provide funds for public policy.[28]

Figure IV: Data and Model Comparison



(a) Fiscal Deficits 1977 - 2016 (b) Monetary Base Growth 1969 - 2016

Source: Banco de México and SHCP.

Notes: The series presented are - Panel **(a)**: in blue the estimated fiscal deficit with the 10^{th}/ 90^{th} percentiles of the estimated deficit distribution. In red/orange the BPT or the RFSP relative to GDP. Panel **(b)**: In blue/red the model/data monetary base annual growth rate, respectively.

Panel **(a)** of Figure IV displays the estimated sequence of fiscal deficits from the model, as well as the BPT and the RFSP relative to GDP between 1977 and 2016. As shown in the Figure, there is an adequate approximation of the model to the BPT data before 1991 and to the RFSP after 1993. During 1991 and 1992, both series show a fiscal surplus. The model cannot match this feature of the data given the assumption of a log-normal distribution, and deficits cannot be negative. Additionally, the model predicts a higher deficit during 1994-1996 relative to those observed in the data; in 1995 the model predicts a fiscal deficit relative to output of 6.1% of GDP, while the RFSP exhibits a fiscal deficit of 2.5% of GDP. The baseline model can only attribute the spike in inflation of that year to fiscal deficits. We will see that the extensions of this model can better account for the rates of inflation during this episode. During 1977-2016, the model's median deficit variance is 53.7% of the

27 The BPT does not consider the revenue and expenditures of Banco de México or the public financial sector. The financial sector of the government includes, among others, trust funds and banks administered by the federal government.

28 For example, during 1990-1998 the government managed a trust fund called FOBAPROA, its objective was to insure private banks against overdue accounts in case of a financial crisis. If the fund provided resources to a private bank to cover its overdue accounts, this would be considered in the RFSP but not in the BPT. The RFSP are a better approximation of the concept of deficits considered in the model. However, before 1990 the only official deficit measure available is the BPT. We are grateful to Nicolas Amoroso, Oscar Budar, and Juan Sherwell for their invaluable guidance in understanding historical accounts and providing these series.

variance presented in the fiscal deficit data.[29]

Panel **(b)** of Figure IV displays the model's implied monetary base growth rate compared with Banco de México's data between 1969 and 1970.[30] The figure shows that the model approximates the data's sequence reasonably well, although there are differences in 1990-1992. The model's monetary base growth rate variance accounts for 82% of the variance presented in the data.

4 Beyond the Baseline Model

Considering that, since 1994, Banco de México has been an independent Central Bank and no longer finances the federal government through money creation, in this section we present modifications to the baseline model.[31] Before we discuss these extensions, we should be explicit about the fact that the model by itself does not distinguish between periods of monetary or fiscal dominance. Formally, the estimation of the model will propose a series of deficits that are financed with monetary emission, while the classification of different periods in terms of the regime rests on the interpretation of the historical narrative we previously presented.[32] In a similar manner, Meza (2017) concludes that the change in legislation that granted independence to Banco de México in 1993 represented a credible change from fiscal to monetary dominance, and that the transition to an independent Central Bank has been successful. Furthermore, Central Bank independence does not imply $d \approx 0$ if the target for inflation is, for example, 3%. Through the lens of the model, the Central Bank would target a long-run level of money growth such that inflation fluctuates around the target of this institution.[33]

The extensions we present will allow us to illustrate some of the channels through which fiscal policy may potentially influence inflation even in a context of autonomy of the Central Bank. These modifications are inspired by the literature that studies the interactions between fiscal and monetary policy, which suggests that, even with an independent Central Bank, fiscal policy can still affect inflation. For example, if agents observe an increasing deficit that translates into higher debt, they may antic-

29 For these results, we considered the BPT before 1991 and the RFSP after this year.

30 To compute the monetary base growth according to the model, we considered equation (1) to show that:

$$\frac{M_t}{M_{t-12}} = \frac{P_t}{P_{t-12}} \left(\frac{1 - \lambda\beta_t}{1 - \lambda\beta_{t-12}} \right).$$

Ramirez de Aguilar (2017) presents further details.

31 As explained by Meza (2017), the Central Bank transfers resources to the Ministry of Finance (equivalent to the Treasury in the United States), after determining its earnings and following legally specified rules. This is called the *Remanente de Operación de Banco de México*. In the United States, the Federal Reserve transfers to the Treasury most of its interest earnings from government debt. As further discussed below, this can be perfectly consistent with a regime of monetary dominance.

32 In this sense, the approach is complementary to models that consider regime-switching environments, e.g., Chung et al. (2007), Cadavid-Sanchez et al. (2017), and Bianchi and Ilut (2017).

33 For the period, Meza (2017) estimates seigniorage at an average of 0.66 p.p. of GDP for the period 1995-2016.

ipate a regime change to make the fiscal path sustainable, hence, they may increase their current inflationary expectations and inflation itself.

First, we present an extension where we consider that the expected inflation rate may be influenced by fluctuations in the nominal exchange rate (NER) between the Mexican peso and the U.S. dollar. An important result of this model is that the effect that the NER has on inflation (known in the literature as Exchange Rate Pass-Through, ERPT) is a function of the fiscal deficit. According to our estimation, in a situation with elevated fiscal deficits that generate high inflation rates, the ERPT is considerable. After 1995, the year in which the NER changed from a fixed to a flexible regime and after Banco de México became an independent institution, the ERPT to inflation and its expectations has become rather limited.

The second extension considers the sovereign interest rate spread EMBI of J.P. Morgan as a variable that reflects the fiscal situation of governments. We estimate that the EMBI has a moderate impact on inflation and its expectations, although its effect is positive and statistically significant. An increase in the EMBI spread is associated with the perception that the government is not in a solid fiscal situation. Hence, following the example illustrated by Kocherlakota (2012), agents may incorporate in their inflation expectations the possibility that the Central Bank may lose independence to the fiscal authority, and consequently raise their inflation expectations. This, according to the model, generates an increase in observed inflation as well.

In the third extension we specify a real-balances demand function that incorporates the exchange rate, as an alternative channel through which this variable may influence inflation.[34]

Empirical evidence shows that sovereign interest rate spreads are, to a large extent, driven by international factors such as risk appetite, market volatility, terms of trade, global liquidity, contagion from events such as the Russian crisis or the LTCM collapse in 1998, and even U.S. macroeconomic news.[35] In the same fashion, exchange rate fluctuations are linked to global financial factors (to give some recent examples, Gabaix and Maggiori (2015) and Itskhoki and Mukhin (2017)), and the Mexican peso is sometimes considered a *commodity currency* (see Kohlscheen (2010)). The state of public accounts can make the economy vulnerable to these external shocks.[36]

Our model allows us to explore empirically the possibility that fiscal policy can make the evolution of inflation sensitive to events in international financial markets. The results motivate the need for further theoretical developments in this area, in par-

34 We have explored additional extensions of the model. For example, incorporating the CETES interest rate, and another specification that includes the target for the inflation rate of Banco de México. However, the fit of these alternative specifications is less favorable (results available upon request). Further exploration of alternative specifications would certainly be an interesting topic for future research.

35 There is an extensive literature that documents these facts, including Longstaff et al. (2011), González-Rozada and Levy-Yeyati (2008), Bunda et al. (2009), Ciarlone et al. (2009), Hilscher and Nosbusch (2010), and Ozatay et al. (2009).

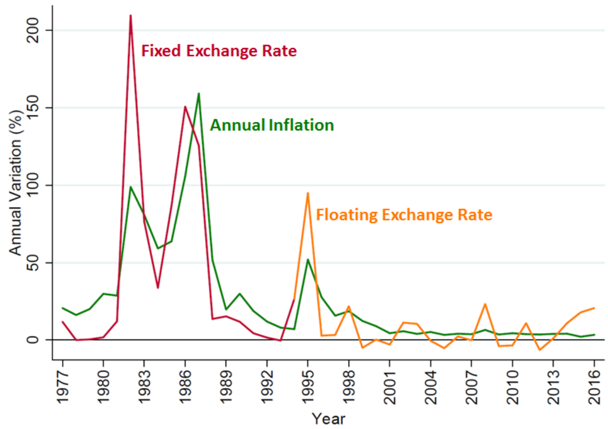
36 The issue of endogeneity is addressed by exploiting alternative methodologies in Cortés-Espada (2013) and Lopez-Villavicencio and Mignon (2016).

ticular for developing economies, where sovereign interest rate spreads and exchange rates seem to be of primary relevance. The historical narrative of events in Mexico for the period 1969-1994 supports this interpretation; events such as significant drops in the price of oil or sudden stops make the economy vulnerable when fiscal accounts are in a dire situation and the government may be forced to turn to the Central Bank to cover its financial needs. Even in a context of *de jure* monetary dominance, economic agents may consider that these risks are still present, and thus we aim to capture this possibility in the estimation of our model.[37]

4.1 The Role of the Exchange Rate

As documented by Rogers and Wang (1994) and Carrasco and Ferreiro (2013), an important variable in determining inflation expectations is the nominal exchange rate (NER). Figure V presents, as a motivation for this extension, the annual inflation rate and the annual variation of the NER between 1977 and 2016. This figure shows a significant correlation between these variables, particularly during episodes of high inflation. An important fact to consider is that before 1995 Mexico had a fixed exchange rate with bounded depreciations.[38] After 1994, the peso-dollar NER entered a floating regime.

Figure V: Annual Inflation and Variation of the NER



Source: Banco de México and INEGI.

In this extension, we consider that the exchange rate variation ΔNER is a variable that can affect inflation expectations. We assume that this variation has a weight ξ on expectations. Hence, for each period t, the expected inflation rate is determined as follows:

$$\beta_t = (1 - \nu - \xi)\beta_{t-1} + \nu\pi_{t-1} + \xi\Delta NER_t. \tag{8}$$

37 These channels have been considered by Zoli (2005) in the case of Brazil, by assessing the impact of *news* concerning fiscal variables and fiscal policy on sovereign interest rate spreads and the exchange rate and discussing the potential implications for monetary policy. Cerisola and Gelos (2005) find that the stance of fiscal policy (proxied by the ratio of the consolidated primary surplus to GDP) is important to determine inflation expectations in the case of Brazil and argue that fiscal policy is instrumental in anchoring inflation expectations.

38 In the Appendix, we describe the different exchange rate regimes in Mexico.

Given that Mexico had a fixed NER during 1969-1994 and after 1995 the NER is in a floating regime, we estimate the model allowing ξ to change during 1969-1994 and 1995-2016. Hence, the model allows agents to give a weight ξ_1 to the NER variation during a fixed exchange rate regime and a weight ξ_2 when the NER is in a floating regime. To estimate this model, again we consider the monthly inflation sequence according to the INPC between January of 1969 and December of 2016, and the sequence of the monthly variation in the peso-dollar NER documented by Banco de México for that period. Table II presents the estimated parameters of this version compared with the baseline model estimation. Considering the exchange rate as a variable that can influence inflation expectations (and hence, inflation), the model can account for 75.8% of the variance observed in the inflation data, while the baseline model can explain 61.6% of this variance. Also, as suggested by the Diebold-Mariano test, during 2000-2016 the NER and baseline models produce different in-sample forecasts of observed inflation (at a 1% significance level) and the modified model has a higher correlation with the inflation data.[39] This result emphasizes the relevance of the exchange rate for the determination of the inflation rate in Mexico.[40]

Table II: Extended Model Parameter Estimation

parameter	NER model	baseline model	description
λ	0.7730 (0.0013)	0.7556 (0.0022)	weight of expectations on the price level
ν	0.1152 (0.0049)	0.1147 (0.0081)	weight of past inflation on expectations
ξ_1	0.0215 (0.0006)	-	weight of NER on expectations in a fixed regime
ξ_2	0.0047 (0.0001)	-	weight of NER on expectations in a floating regime
$\bar{d}_1$	0.0077 (0.0001)	0.0075 (0.0001)	monthly *high* median level of fiscal deficits
$\bar{d}_2$	0.0039 (0.0003)	0.0039 (0.0004)	monthly *moderate* median level of fiscal deficits
$\bar{d}_3$	0.0022 (0.0003)	0.0023 (0.0002)	monthly *low* median level of fiscal deficits

Notes: The numbers shown in parentheses represent the standard error of each parameter, computed using the Hessian matrix of the maximum likelihood problem (see MacDonald and Zuccini (2009)).

The parameters $\{\xi_1, \xi_2\}$ are statistically different, a result that can be interpreted as follows: between 1969 and 1994 the ERPT to expectations was 0.0215 p.p. given a 1% depreciation of the NER. After 1995 the ERPT shows a considerable reduction: a 1% exchange rate depreciation translates to an increase in the expected inflation rate of 0.0047 p.p. To assess the ERPT into the observed inflation, we must consider not only the ERPT to expectations, but also the fiscal deficit level relative to GDP. This is because, within the model, both variables jointly determine the inflation rate.

39 The hypothesis test proposed in Diebold and Mariano (1995) allows to assess if two forecasts $\{y_{it}, y_{jt}\}_{t=1}^{T}$ related to a series $\{y_t\}_{t=1}^{T}$ are statistically different. Defining $e_{kt} = y_{kt} - y_t$ for $k \in \{i, j\}$ and considering a loss-function $g(e)$, the null hypothesis in the Diebold-Mariano test is that $\mathbb{E}[g(e_{it}) - g(e_{jt})] = 0$. These authors construct a statistic function that involves the autocorrelations of the forecasts and show that, if the time series considered are covariance stationary and short memory, it has a t-Student distribution. Then, they construct a statistic that, under the same assumptions, is asymptotically $N(0, 1)$.

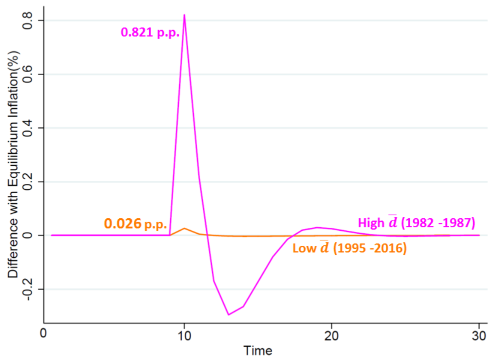
40 More formally, according to the SIC comparison, the ordering of the models is the following: the model with the EMBI spread and the NER in the formation of expectations, the model with the NER in the real balances demand function (presented in the following section), the model with only the NER in the formation of expectations and, finally, the baseline model.

As we detailed in the previous section, a higher fiscal deficit magnifies the effect that β_t has on inflation (in fact this effect is nonlinear). Hence, if fiscal deficit increases, the effect that the NER variation has on π_t will grow because this variation affects β_t. It can be shown that:

$$\frac{\partial \pi_t}{\partial \Delta NER} = \frac{\partial \pi_t}{\partial \beta_t}\frac{\partial \beta_t}{\partial \Delta NER} = \frac{\lambda \xi}{1-\lambda\beta_t - d_t}\pi_t. \tag{9}$$

This equation highlights two important results: i) the ERPT is increasing in d_t and ii) a higher inflation rate implies a higher ERPT. Figure VI shows the impulse-response function of inflation given a 1% depreciation in the NER. As this figure suggests, when fiscal deficit is high (e.g., during 1982-1987) the ERPT to inflation is 0.821 p.p. However, if fiscal deficit is low the ERPT of a 1% depreciation is 0.026 p.p. Hence, a low fiscal deficit financed by the Central Bank not only translates into low inflation, but also into a limited ERPT. A low pass-through contributes to a steady and anchored expected and observed inflation rate.[41]

Figure VI: Impulse-Response Functions of Inflation



Notes: This figure displays the impulse-response function of inflation given a 1% shock in the NER during $t = 10$. The inflation equilibrium is computed recursively considering a constant fiscal deficit and iterating until the observed and expected inflation are constant.

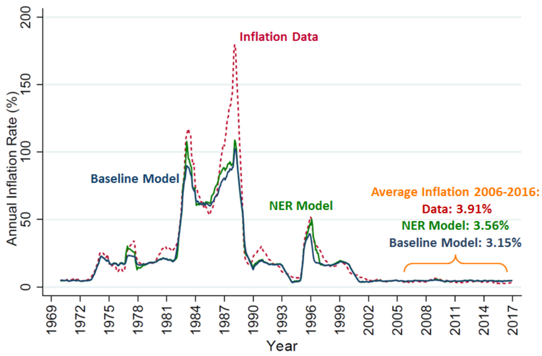
Figure VII shows that the model that considers the NER as a variable that influences inflation expectations is able to provide a better account of the behavior of inflation dynamics in general, but especially during 1982 and 1994-1995, relative to the model that does not consider the NER, given the depreciation of the NER observed during those years.

4.2 The Role of the EMBI Spread

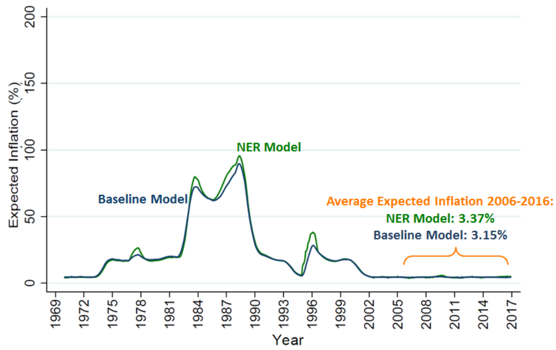
In this section we analyze an extension of the baseline model that considers the sovereign interest rate spread EMBI, a variable that captures the perception of the

41 The low level of pass-through is consistent with estimates in the literature for Mexico, see Albagli et al. (2015), Capistrán et al. (2011), Cortés-Espada (2013), and Kochen and Samano (2016). Furthermore, there is evidence of a declining ERPT in environments with more stable inflation and with the adoption of inflation targets (see Baqueiro et al. (2003), Choudhri and Hakura (2006) and Lopez-Villavicencio and Mignon (2016)). Capistrán et al. (2011) and Cortés-Espada (2013) document a lower ERPT for Mexico under the inflation targeting regime.

Figure VII: Inflation and Expectations in the NER Model



(a) Annual Inflation



(b) Expected Inflation

Source: INEGI.

fiscal situation in Mexico and may influence inflation expectations. To the extent that this variable is relevant according to the estimation, this would suggest that, even though Mexico has an independent Central Bank, fiscal policy must be relevant for monetary policy through its influence on the inflation rate and its expectations.[42]

As a motivation for this extension, Figure VIII displays, in Panel **(a)**, the interest rate spread EMBI and the NER between 1998 and 2016. This figure shows that these variables are weakly correlated. Hence, if we consider the EMBI and the NER, we will be able to identify the effect that each variable has on inflation and its expectations. Panel **(b)** of this figure shows the relationship between the annual inflation rate and the variation (in basis points) of the EMBI spread.

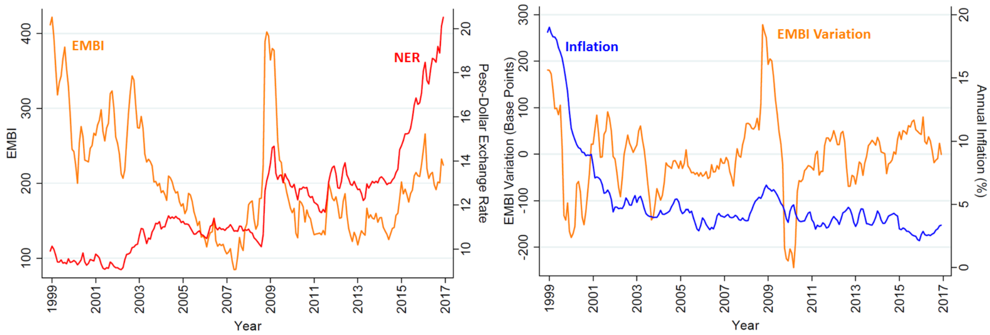
In this extension, we consider two regimes: a fiscal dominance regime, where the fiscal authority can use money creation to finance its deficit, and Central Bank autonomy, where it cannot. The interpretation we propose is that Mexico had a fiscal dominance regime between 1969 and 1994. Under fiscal dominance, Mexico had a fixed NER and under monetary dominance, the peso-dollar NER is under a floating regime (see the Appendix for a more detailed description of the exchange rate regimes). We assume that under fiscal dominance, agents determine their expectations according to:

$$\beta_t = (1 - \nu_1 - \xi_1)\beta_{t-1} + \nu_1 \pi_{t-1} + \xi_1 \Delta NER_t. \tag{10}$$

After 1994 we allow agents to give some weight σ to the current fiscal situation (which is reflected in the sovereign EMBI spread). Hence, agents determine their

42 The perception of economic agents of the fiscal responsibility of the government may depend on the particular historical context. For example, Sargent and Zeira (2011) describe how the anticipation of a future government bailout of banks caused a jump in inflation in Israel in 1983. They argue that the public anticipated that this bailout would eventually be financed by monetary expansion. Alternatively, Chung et al. (2007) explore an environment where monetary and fiscal regimes evolve according to a Markov process, this possibility can change the impact of policy shocks. These authors argue that, to the extent that there has been a history of changes in policy regimes, private agents can ascribe a probability distribution over the different regimes.

Figure VIII: EMBI, NER, and Inflation



(a) EMBI and NER (b) EMBI Variation and Inflation

Source: Banco de México, Bloomberg, and INEGI.

inflation expectations according to:

$$\beta_t = (1 - \nu_2 - \xi_2 - \sigma)\beta_{t-1} + \nu_2\pi_{t-1} + \xi_2 \Delta NER + \sigma \Delta EMBI_t. \tag{11}$$

We allow the parameters $\{\nu, \xi\}$ to vary because the NER had a change in its regime.

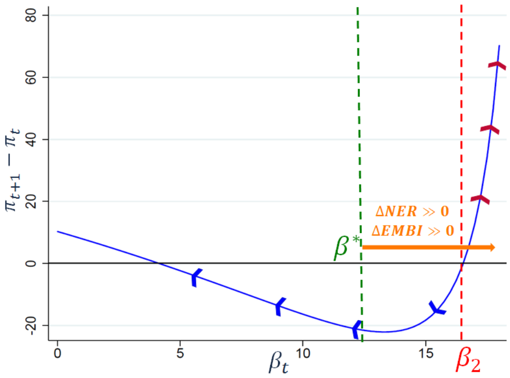
If parameters ξ and σ are positive and statistically significant, it would imply that the EMBI spread and the NER influence inflation. In fact, these variables can generate the escape dynamics that in the baseline model could only be ignited by the behavior of fiscal deficits.[43] Figure IX exemplifies how an escape dynamics that leads to high inflation or hyperinflation can occur in this scenario: suppose that initially $\beta_t = \beta^*$ and that ΔNER_t, $\Delta EMBI_t$ are limited. This implies that inflation and its expectations will converge to a low inflation equilibrium, as the blue arrows show. However, if the fiscal authority starts to considerably increase its deficit (which is no longer financed with money creation and is therefore translated into debt) this would be reflected in the EMBI spread and influence the NER. In our model, the increment in these variables will affect inflation expectations. Furthermore, if this effect is large enough, as shown with an orange arrow in the Figure, it will cause that $\beta_t > \beta_2$, which will lead to high inflation (as shown with red arrows). Consequently, if σ and ξ are significant and positive then, even in a context of monetary dominance, our model suggests the possibility of high inflation caused by the fiscal authority via expectations.

To estimate this model, once again we consider the inflation sequence according to the INPC during 1969-2016, the NER variation registered by Banco de México, and the EMBI spread reported by Bloomberg after 1994. The main results of this extension are:

- The estimation for σ suggests that, everything else constant, if the EMBI

43 In the baseline model, an escape dynamics can only occur if fiscal deficit increases for a considerable period, because it is the only way to raise inflation expectations.

Figure IX: Escape Dynamics in the Modified Model



Notes: This figure considers $\beta_{t-1} = 1.02$ and the estimated parameters of the EMBI extension.

spread increases 100 basis points, the rate of inflation rises by 0.24 p.p.[44]

- On the other hand, the estimation of ξ_2 implies that under monetary dominance the inflation rate increases 0.011 p.p. given a 1% depreciation of the NER.
- Finally, with this specification for inflation expectations, the model estimates that $\bar{d}(3)$ is almost zero, which is the deficit regime for the period of independence of the Central Bank.

Figure X shows that, if we consider the interest rate spread EMBI and the NER, then the inflation generated by this model is closer to the inflation sequence presented in the data. Actually, the incorporation of these variables allows the model to explain 0.65 p.p. more of the inflation rate during 2006-2016 compared to the baseline model. The Diebold-Mariano test also suggests that the in-sample forecast for the inflation sequence between these years is statistically different (at a 1% confidence level) between the EMBI extension and the baseline model. Hence, these extensions suggest that the fiscal situation, to some extent, have caused the inflation rate to be above Banco de México's inflation target of 3%.

4.3 The Exchange Rate: An Alternative Channel

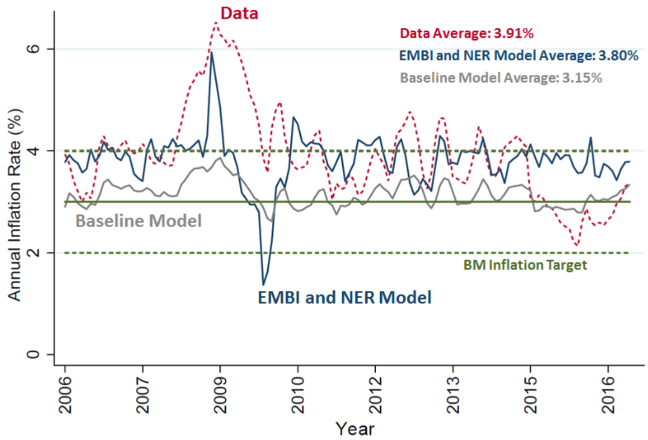
A variable such as the exchange rate may affect inflation through several channels and not only through inflation expectations. We now discuss an extension where the NER has an effect on inflation through its direct influence on the price level P_t. We assume that $P_t = \gamma M_t + \lambda P^e_{t+1} + \psi NER_t$.[45] Hence, the NER has a weight ψ on the price level, parameter that can be interpreted as the pass-through of the NER to the price level. This modification implies that the inflation rate is now given by the following expression:

$$\pi_t = \frac{\theta\,(1 - \lambda\beta_{t-1} - \psi NER_{t-1})}{1 - \lambda\beta_t - \psi NER_t - \gamma d_t}. \tag{12}$$

44 To find the impact that the EMBI spread has on inflation, we again have to consider an impulse-response function as in Figure VI.

45 Alternatively, this expression can be rewritten as a demand for real balances that depends on the exchange rate.

Figure X: Evolution of Inflation: Models and Data during 2006-2016



Source: Banco de México, Bloomberg, and INEGI.

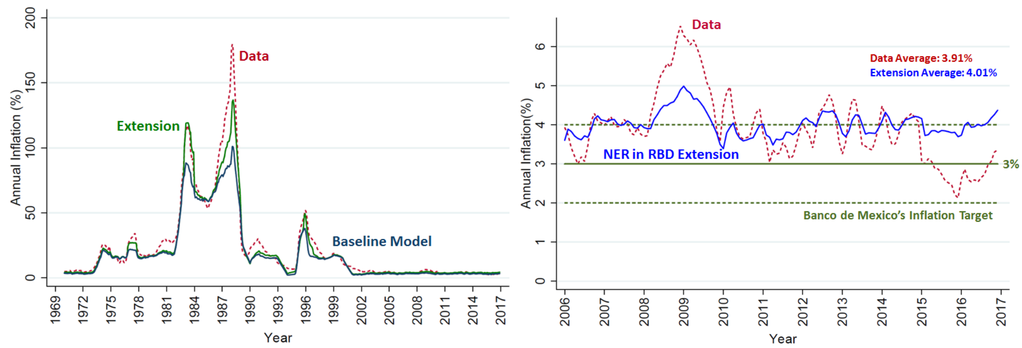
Expectations are given by the CGE algorithm $\beta_{t+1} = (1-\nu)\beta_t + \nu\pi_t$, when there is fiscal dominance (i.e., before 1994) and by $\beta_{t+1} = (1-\nu-\sigma)\beta_t + \nu\pi_t + \sigma\Delta EMBI_t$ under Central Bank independence. The main difference between assuming that the NER affects expectations or P_t is that, in this extension, inflation is a function of the NER dynamics in two consecutive periods: (NER_{t-1}, NER_t). Hence, if the NER depreciates considerably between $t-1$ and t, this will have a higher impact on inflation and on future inflationary expectations.

Figure XI presents the main results of this extension. As this figure shows, the extended model better accounts for the inflation rate during 1970-2016 than the baseline model. This model performs particularly better in those periods in which the NER registers a considerable depreciation. For example, during 1982, the peso-dollar NER suffered a depreciation of over 200% and the model predicts that inflation at the end of that year was 118.1%. Additionally, during 1995 the NER had a depreciation that surpassed 100%, which implied, according to the model, an inflation of 49.1% by the end of this year.

Although this extension provides a good approximation to the data, according to the Diebold-Mariano test and the SIC criterion the model that incorporates the NER and EMBI in the formation of expectations has a better fit.[46] This result highlights the role that both variables have on the expectations formation process and, therefore, suggest that even though Mexico has an independent Central Bank, fiscal policy can still influence expectations and, consequently, inflation itself.

46 In Section 4.1 we provide the ordering of the models according to the SIC criterion.

Figure XI: Inflation in the Extended Model



(a) 1970-2016 (b) 2006-2016

Source: Banco de México and INEGI.

5 Concluding Remarks

The baseline model and the extensions that we have presented allow us to assess the role of fiscal policy in the determination of inflation and its expectations. Even in a context of Central Bank independence, a large literature has explored the role of fiscal policy in determining inflation. We exploit a simple model and provide evidence of the relevance of fiscal policy in determining the behavior of aggregate prices in Mexico as well as the importance of expectations.

Admittedly, the theoretical framework we utilize is relatively simple and models with more structure, perhaps in the inter-temporal dimension, would increase our understanding of the relationship between fiscal policy and inflation in emerging economies. Furthermore, it is sometimes argued that Central Bank independence acts as a mechanism that increases fiscal responsibility of the government in developing countries (Bodea and Higashijima (2015), Minea and Tapsoba (2014)). We believe further research is necessary to understand the institutional arrangements that govern the relationship between a Central Bank and the Fiscal Authority in the presence of competing objectives and constraints.

6 Appendix

6.1 Parameter Estimation

The following equations, together with transition matrices $\{Q_d, Q_v\}$ define inflation, expected inflation, and fiscal deficits at each t according to the baseline model:

$$\pi_t = \mathcal{X}_t \frac{\theta(1-\lambda\beta_{t-1})}{1-\lambda\beta_t - \gamma d_t} + (1-\mathcal{X}_t)\,\pi_t^\star(d_t),$$

$$\beta_{t+1} = (1-\nu)\beta_t + \pi_t, \quad log(d_t|\bar{d}_t, v_t) \sim N(log(\bar{d}_t), v_t),$$

where $\mathcal{X}_t$ is a constant equal to 1 if $\{\pi_t, \beta_t.d_t\}$ satisfy $1-\lambda\beta_{t-1} > 0$ and $\delta(1-\lambda\beta_t - \gamma d_t) > \theta(1-\lambda\beta_{t-1})$.[47] Assuming $\beta_0 = \pi_0$ and given a sequence of fiscal deficits $\{d_t\}_{t=0}^T$, the model can generate a sequence for the expected inflation rate $\{\beta_t\}_{t=0}^T$ and for the actual inflation rate $\{\pi_t\}_{t=0}^T$. However, the hidden Markov states $\{\bar{d}, v\}$, among other parameters, must be estimated to generate a sequence of fiscal deficits. Table III shows the parameters that need to be estimated.

Table III: Model Parameters

parameter	restrictions	description
λ	$0 < \lambda < 1$	weight of expectations on the price level
ν	$0 < \nu < 1$	weight of past inflation on expectations
γ	$\gamma > 0$	weight of monetary base on the price level
θ	$0 < \theta < 1$	persistence of the monetary base
δ	$\delta > 0$	constant that bounds inflation
$\bar{d}_1, \bar{d}_2, \ldots, \bar{d}_D$	$\bar{d}_1 > \bar{d}_2 > \ldots > \bar{d}_D > 0$	median values of fiscal deficits
$v_1, v_2, \ldots, v_V$	$v_1 > v_2 > \ldots > v_V > 0$	variance values of fiscal deficits
v_π	$v_\pi > 0$	inflation variance when determined randomly
p_{ij}^d	$0 \le p_{i,j}^d \le 1,\ \sum_j p_{i,j}^d = 1$	i, j-component of the transition matrix Q_d
p_{ij}^v	$0 \le p_{i,j}^v \le 1,\ \sum_j p_{i,j}^v = 1$	i, j-component of the transition matrix Q_v

Let ϕ be the vector of all the parameters in the model. Given that d_t is a random variable and because $\{\pi_t, \beta_t\}$ are a function of fiscal deficits, we can construct a joint density function for a sequence of T periods of inflation, its expectations and fiscal deficit: $p(\pi^T, \beta^T, d^T|\phi)$. If there were available data on inflation, its expectations and fiscal deficit for a large T, the estimated parameters $\hat{\phi}$ can be obtained using the maximum-likelihood method applied to the joint density $p(\pi^T, \beta^T, d^T|\phi)$. However, data on inflation expectations and fiscal deficit are hard to find for a large T, or may not be reliable. Furthermore, we find that historical series often go through methodological modifications. This is particularly true in the case of Mexico, as we have already discussed.

INPC (consumer price index) data are available since January 1969 at a monthly frequency. Therefore, to estimate the parameters we use the marginal density of a sequence of inflation π^T between January of 1969 and December of 2016. This

47 These constraints guarantee that the model's inflation rate is bounded and that the real balances demand is positive.

marginal density is denoted $p(\pi^T|\phi)$. The estimated parameters are obtained as the vector $\hat{\phi}$ that maximizes $p(\pi^T|\phi)$ given the gross inflation rate sequence π^T (subject to constraints):

$$\hat{\phi} = \text{argmax}_{\phi\in\Omega} \;\; p(\pi^T|\phi), \tag{13}$$

where Ω is the set of all the vectors ϕ that satisfy the constraints relevant for each parameter. Because there is no analytical solution to this maximization problem, $\hat{\phi}$ has to be approximated numerically. To do this, we used a constrained optimization algorithm based on the BFGS (Broyden-Fletcher-Goldfarb-Shanno) method of Nocedal and Wright (2006) and the block-wise method of Sims et al. (2006).

Given the computational burden of the maximum-likelihood optimization problem, Sargent et al. (2009) fix three parameters to reduce the complexity on the estimation. These parameters are: $\theta = 0.99$, $\delta = 100$, and $\gamma = 1$. The value assigned to θ is consistent with the behavior of nominal balances in the five countries these authors studied. Fixing $\delta = 100$ implies that, in every period, inflation cannot surpass 10,000%. Finally, γ was fixed because the maximum-likelihood algorithm cannot identify γ and d_t separately. Once d_t is estimated for each period, γ is re-normalized so that the mean of fiscal deficits estimated by the model matches the mean observed in the data (in our case, for Mexico for the period 1977-2016).

6.2 Adaptive vs. Rational Expectations

In this part of the Appendix we discuss some of the implications that rational expectations have in the baseline model presented in this paper. Additionally, we compare the main differences induced in the dynamics of the model between these types of expectations and CGE. One way of modeling that agents are rational when forming their beliefs on future inflation is to assume:

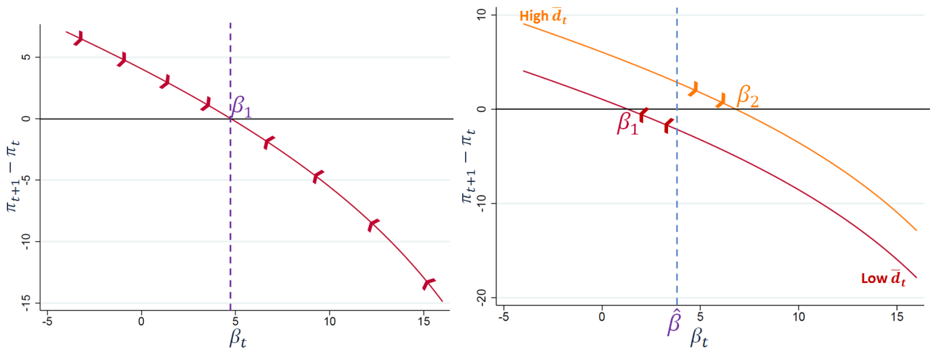
$$\beta_{t+1} = \mathbb{E}_t[\pi_{t+1}|\bar{d}_t, v_t]. \tag{14}$$

Equation (14) points out one important difference between rational expectations and CGE in this model. If agents are rational, they condition their expectations on the median level $\bar{d}_t$ and the variance v_t of current fiscal deficit since the evolution of the median and variance of fiscal deficit is known to agents when they are rational. Assuming CGE does not require agents to condition their expectations on $\{\bar{d}_{t+1}, v_{t+1}\}$ because they update their beliefs according to (4).

Assuming rational expectations also affects the dynamics between the gross inflation rate of two consecutive periods $\{\pi_t, \pi_{t+1}\}$ as a function of β_t. Panel **(a)** of Figure XII plots $\pi_{t+1} - \pi_t$ as a function of β_t assuming β_{t+1} is determined according to (14) and using the same median and variance of fiscal deficit in t and $t + 1$. As this figure shows, there is only one value of β_t that induce a constant inflation (and expectations) over time (β_1). As the figure suggests, β_1 is a stable equilibrium. Thus, if fiscal deficit remains with the same median and variance level, $\pi_{t+1} - \pi_t$ will converge to zero and β_t to β_1.

With rational expectations, contrary to CGE, if inflation is high ($\beta_t > \beta_1$), agents will not allow their expectations to provoke the escape dynamics. Their expectations will adjust and converge to β_1. However, the government could prevent expectations from converging to a high inflation equilibrium by reducing its fiscal deficits as shown in Panel **(b)** of Figure XII. This figure plots $\pi_{t+1} - \pi_t$ as a function of β_t for two different $\bar{d}$ values (low and high). Assuming $\beta = \hat{\beta}$ and that the median fiscal deficit level is high, if the government continues with this deficit level, inflation will converge to a high equilibrium and its expectations to β_2. However, if the government reduces its fiscal deficits, it will change the dynamics on inflation and its expectations inducing a convergence to β_1.

Figure XII: Dynamics Induced by Rational Expectations



(a) Inflation and Expectations (b) Deficit, Inflation and Expectations

Notes: These figures consider $\beta_{t-1} = 1.02$ and the estimated parameters shown in Table I.

Figure XII points out an important difference between rational expectations and CGE: when agents use the CGE algorithm, if the inflation rate induces a high β_t then this could provoke an escape dynamics and eventually a hyperinflation episode, where the dynamics between inflation and its expectations are unbounded. However, with rational expectations, even with an extremely high fiscal deficit, agents always adapt their expectations to prevent a hyperinflation spiral. If the fiscal deficit is high, rational expectations imply a stable equilibrium with a high inflation rate and no escapes.

Even though CGE and rational expectations induce different dynamics on the variables involved in the model, the inflation equilibria they predict are similar. Sargent et al. (2009) argue that, in the context of hyperinflation models, "an adaptive expectations version of the model shares steady states with the rational expectations version, but has more plausible out-of-steady state dynamics." Besides, rational expectations may induce multiple equilibria that are hard to compute. Given the computational problem rational expectations may induce and the fact that some Latin American countries have experienced hyperinflation episodes with escape dynamics which a strictly rational expectations model cannot account for, CGE are necessary for the purposes of this study.

6.3 Exchange Rate Regimes

The table in this Annex presents the different regimes that the peso-dollar NER has had between 1954 and 2016. Before 1994, this NER had several regimes that can be considered slight variations of a fixed NER rule. For example: i) controlled variation, in which the Banco de México established an interval in which the NER was allowed to vary; ii) generalized controlled system, in which all credit institutions needed an authorization from the Central Bank to sell or buy currencies; and iii) controlled flotation, in which Banco de México established an interval, changed daily, within which the NER was allowed to fluctuate.

Table IV: Exchange Rate Regimes In Mexico During 1954-2016

Date		Regime	NER	
Beginning	End		Beginning	End
April 1954	August 1976	Fixed	12.50	12.50
September 1976	August 1982	Controlled Variation	20.50	48.80
September 1982	December 1982	Generalized Controlled System	50.00	70.00
December 1982	August 1985	Controlled System	95.00	281.30
August 1985	November 1991	Controlled Flotation	282.30	3,073.00
November 1991	December 1994	Floating Intervals with Controlled Variation	3,074.10	N 3.99
December 1994	December 2016	Floating	N 4.88	N 20.51

Source: Banco de México.

Notes: N denotes New Mexican Pesos.

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