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WHAT DOES BANXICO CARE ABOUT? BAYESIAN ESTIMATION OF THE PREFERENCES OF THE MEXICAN CENTRAL BANK

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Resumen

El objetivo principal de este trabajo es estimar las preferencias que Banco de México tiene sobre cuatro objetivos distintos de política monetaria: estabilización del crecimiento, control de la inflación, “suavizamiento” de la tasa de interés y reducción de la volatilidad del tipo de cambio. Específicamente, analizo el periodo de 2000 a 2013, desde la adopción del régimen de objetivos de inflación por parte de Banco de México. Para esto, utilizo un modelo macroeconómico Nuevo Keynesiano para una economía pequeña y abierta y es estimado utilizando técnicas Bayesianas. Los resultados permiten afirmar que si bien el principal objetivo de política monetaria en México es la estabilización de la inflación, existen otros objetivos subyacentes que también son importantes para el banco central mexicano.

Abstract

The main objective of this work is to estimate the preferences the Mexican Central Bank over four different objectives of monetary policy: growth stabilization, inflation control, interest rate "smoothing", and reduction of exchange rate volatility. Specifically, I analyze the period 2000-2013, since the adoption of the inflation targeting regime by Banco de México. For this, I use a New Keynesian macroeconomic model for a small open economy and it is estimated using Bayesian techniques. The results show that even if the main objective of monetary policy in Mexico has been inflation stabilization, there are other underlying objectives which are also important for the Mexican central bank.

Contents

1 Introduction

Although the Mexican Central Bank (Banxico) was created in 1925, it only acquired its independence in 1994. Along with their autonomy, Banxico received its primary and only objective in terms of monetary policy: to maintain the stability of prices.[1] The new institutional framework paved the way for a later implementation of the inflation targeting (IT) regime, a system widely used by developed and developing countries.

Even though there has not been any major problem with inflation since the instalment of IT in 2001, Mexico has been struck with some economic recessions and decelerations during this period, the last one of them being in 2013. The Survey on the Expectations of Private Sector Economics Specialists published by Banxico in January of 2013 states that specialists expected a growth rate of 3.55%, but the actual performance, according to official estimates, was a modest growth of 1.1%.[2] Favoring (recently) the short-term nominal interest rate as policy instrument, Banxico explicitly aims to achieve the convergence of inflation to its target level in the medium-run. However, it is plausible that implicit additional objectives also guide policy. During 2013, Banxico reduced three times the interest rate, maybe showing some concern over the negative output gap. Although inflation hasn't gone over the 3% limit, this behavior might suggest some preferences of the Mexican Central Bank over economic growth.

In this paper, I estimate Banxico's preferences under the IT regime over four specific policy objectives: inflation control, output stabilization, exchange rate volatility reduction and targeted interest rate smoothing. Specifically, I follow the work of Kam, Lees and Liu (2009), which uses as a theoretical basis a New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model for a small open economy and Bayesian methods for the estimation stage. I aim to study what policy goals are important for Banxico, assuming a monetary policy that systematically minimizes an intertemporal quadratic loss function under discretion in a forward-looking model.

How can Banxico aim for other policy objectives when the law clearly states that there shouldn't be any other objective but reducing inflation? As Svensson (1999) argues, IT can be interpreted as the announcement and assignment of a relatively specific loss function to be minimized by the central bank. The loss function can include other variables, not just inflation. However, we don't know which variables do enter in the loss function. Monetary

[1]The exact words are "to maintain the stability of the purchasing power of the local currency", stated in Article 2 in the Act of Banco de México.

[2]As stated by the official bulletin number 95/14, published by the National Institute of Statistics and Geography (INEGI) in februrary of 2014.

policy makers are hardly transparent with respect to their preferences. Banxico has a clear price stability mandate and publicly announces a numerical inflation target, but it is much less explicit with respect to other goals. This is not particular of the Mexican case, it is easily notable for other countries that work under a "flexible" IT.[3] In other words, from the perspective of IT, policymakers use their monetary policy instruments to achieve targets for variables such as inflation or output. The weight assigned to each objective depends on the institutional preferences assigned to the achievement of the aforementioned goals. What if Banxico gives a relatively high weight, not only to stabilizing prices, but also to stabilizing output or minimizing exchange rate volatility? Determining the preferences of the central bank allows us to know what variables it does consider relevant. Is the obtained result something which was actually sought by the Central Bank or just a favorable random circumstance?

This paper contributes to the current literature by offering a first study for the Mexican case. As Castelnuovo and Surico (2003) point out, estimating a central bank's preference parameter can be substantially informative for three reasons. First, it improves our understanding of policy actions. Banxico's decisions can be more easily interpreted once its objectives are identified. Second, it helps to evaluate the performance of Banxico's monetary policy by comparing the actual result to the targeted objectives. Finally, we can compare optimal and observed interest rates, since an optimal rule can only be derived once we know the preference parameters.

It is important to note that while I intend to show information on Banxico's policy preferences since IT instalment in 2001, I do not intend to make any value judgement on these preferences. There is plenty of literature that has already studied the performance of IT in Mexico and other countries (e. g. Ball and Reyes, 2004; Capistrán and Ramos-Francia, 2010; Carrasco and Ferreiro, 2013). The sole objective of this work is to uncover Banxico's preferences over certain macroeconomic objectives.

Using DSGE models presents some advantages over other methods used in the current central bank preference estimation literature. By incorporating forward looking variables, DSGE models are not vulnerable to the Lucas critique and they allow us to examine social welfare.

In this particular work, Kam, Lees and Liu (2009) model of a small open economy with low exchange rate pass-through, based on Monacelli (2005), provides an excellent framework for the Mexican case. Some authors have already shown incomplete exchange rate pass-through

[3] As a matter of fact, New Zealand, the first country to work under an IT regime, includes a clause in its Policy Targets Agreements, declaring that as the Central Bank implements monetary policy to achieve price stability, it "shall seek to avoid unnecessary instability in output, interest rates and the exchange rate".

in Mexico. Capistrán et al. (2011) find that exchange rate pass-through to consumer prices is below 20 percent, while Cortés-Espada (2013) finds that exchange rate pass-through to the general price level is low and not statistically significant.

In spite of the advantages that DSGE models present, given the highly nonlinear nature of these models, estimation by traditional methods is often difficult if not impossible. As An and Schorfheide (2007) describe, econometrics on DSGE models have to cope with several challenges, including potential model misspecifications and identification problems. A Bayesian framework will allow us to overcome these hurdles.

The paper is organized as follows. Section 2 describes the related literature. Section 3 introduces the theoretical model. Section 4 describes the data and explains the estimation strategy. Section 5 shows my main results and Section 6 concludes.

2 Literature Review

Ever since the seminal work of Taylor (1993), some specific monetary rules have been proposed to describe the response of central banks to economic variables. In DSGE models, central bank behavior is often modeled by some type of reduced-form monetary rule. Nonetheless, the coefficients estimated for these rules do not necessarily reflect the Central Bank's preferences. Changes in the policy rule could originate because of changes in the economic structure or from changes in policy preferences.

One of the first studies to report estimates of the preferences of a monetary authority is Salemi (1995). He uses a vector autoregressive model to estimate the objectives of the U.S. Federal Reserve (FED). Since then, a considerable number of researchers have focused on policymaker's preferences for the American case. For example, Favero and Rovelli (2003), Castelnuovo and Surico (2004) and Dennis (2006) use a three-equation New Keynesian framework[4] and find that during the Volcker-Greenspan period, contrary to the FED's double mandate, a very small or insignificant weight was given to output stabilization. Soderlind et al. (2002), show that the low (or zero) weight assigned to output stabilization is necessary to match the low volatility in inflation and the high volatility in output that are observed in US data. In addition to these results, Dennis (2006) finds that the FED assigns a high weight to interest rate smoothing. Using a different methodology, Kilian and Manganelli (2008) study the FED's

[4]Namely, an aggregate demand, an aggregate supply equation and a monetary rule equation that solves for central bank's optimization problem.

policy actions as the outcome of a risk management problem and estimate the risk aversion parameters of the FED during the Greenspan period.

Even though many papers focus on the FED, there has been a growing literature that tries to estimate central bank preferences for other countries' central banks. Assenmancher-Wesche (2006) estimates the monetary policy reaction functions for the US, the United Kingdom, and Germany, using a Markov-switching model that allows for shifts in the coefficients of the central bank's reaction function. This work shows that the Bundesbank has placed a relatively higher weight on inflation than the FED. Cecchetti and Ehrmann (1999) estimate preferences for 23 countries (including inflation targeters like Australia, Canada, Chile and New Zealand). They find evidence that aversion to inflation variablility rises substantially immediately after the targeting regime is implemented. Cecchetti et al. (2002) estimate preferences for central banks of countries in the European Monetary Union. In both studies, the authors use a structural VAR that has little dynamic structure. Based on Cecchetti et al. (2002), Arestis et al. (2010) estimate central bank preferences of the Euro area and the UK. They introduce dynamics into the model and allow policy preferences to be asymmetric. They find that the Euro countries put more weight on inflation than the UK. Tachibana (2003) estimates the preferences for Japan, the UK and the U.S. He puts special attention to the period after the first oil shock and shows that these countries increased their aversion to inflation volatility due to this shock. Rodriguez (2006) estimates the preferences for the Bank of Canada for different subsamples and finds evidence that the parameter associated with the implicit inflation target has significantly decreased.

A small portion of this literature has focused on Latin-American countries, maybe due to the instalment of an IT regime in many of them.[5] Silva and Portugal (2009) and Cabrera et al. (2012) identify the preferences of the Central Bank of Brazil and for the Central Reserve Bank of Peru, respectively. They both use a relatively simple calibration process for the Rudebusch and Svensson (1998) four-equation model. As far as I know, nothing of this sort has been done for the Mexican case.

Despite the recent popularity of DSGE models and Bayesian estimation, few works have used them for central bank's preferences estimation. Kam, Lees and Liu (2009) is the first to estimate the central bank preferences for Australia, New Zealand and Canada; three of the

[5] According to Schmidt et al. (2002), IT in Latin-America has been adopted by Chile (in 1990), Peru (1994), Mexico (1999), Brazil (1999), and Colombia (1999).

major small open economies that operate under the IT regime. The authors use a DSGE model based on Monacelli (2005), adding a central bank that minimizes a quadratic loss function under the discretionary case. Similarly, Remo and Vasicek (2009) use the DSGE model based on Gali and Monacelli (2008) for the Czech National Bank. For this paper, I will follow the methodology proposed by Kam, Lees and Liu (2009).

In DSGE empirical applications, the estimation strategy plays a very importante role. Since the seminal work of Kydland and Prescott (1982), trying to use DSGE models as foundational empirical models, new methodologies were developed. The present empirical methodologies have been used in this literature: calibration, general method of moments, maximum likelihood (ML) estimation, and Bayesian estimation.[6]

Similar to my current approach, Ilbas (2010) and Ilbas (2012) estimate the preferences for the European Central Bank (ECB) and the FED using Bayesian techniques, respectively. Ilbas (2010) uses the famous Smets and Wouters (2003) model for the Euro area, while Ilbas (2012) uses Smets and Wouters (2007) model for the US. A key difference from Kam, Lees and Liu (2009) is that she assumes optimal monetary policy under commitment, while the latter uses discretion.

Bayesian estimation provides some advantages over the aforementioned methods. Specifically, Mancini (2013) mentions five. First, as opposed to other estimation strategies based on particular equilibrium relationships, Bayesian estimation fits the complete, solved DSGE model.

Second, when using ML, data may not be informative enough and the likelihood function can be flat in some directions, thus presenting a problem of identification. Prior distributions used in Bayesian methods allow the posterior distribution to avoid peaking at strange points.

Third, if we estimate parameters using ML a problem of identification may arise. The posterior distribution of a parameter can be flat over a subspace, complicating numerical maximization. As we add prior distributions we also add enough curvature in the posterior distribution to facilitate numerical maximization.

Fourth, DSGE models are often misspecified. Bayesian methods addresses this problem by adding shocks, which can be interpreted as observation errors.

Finally, when using Bayesian estimation with different models we can estimate different models and determine which model best fits the data.

[6]Dennis (2004, 2006) and Ozlale (2003) use maximum likelihood; Favero and Rovelli (2003), on general method of moments; Soderlind et al. (2002) and Castelnuevo and Surico (2003), on a calibration process.

3 Theoretical Model

As we have described before, the Kam, Lees and Liu (2009) paper is based on Monacelli (2005) and is very similar to Justiniano and Preston (2010) model. This model follows the New Keynesian approach to macroeconomics. Some key elements and properties are monopolistic competition and nominal rigidities. Short run non-neutrality of monetary policy arises as a consequence of these features. Because monetary policy plays a fundamental role, New Keynesian models have emerged as the workhorse for the analysis of monetary policy and its implications for inflation, economic fluctuations, and welfare.[7]

Particularly, an important feature of this model is the existence of incomplete exchange rate pass-through. Allowing for deviations from the law of one price will generate a trade-off between the output gap and stabilization of inflation. Monacelli's (2005) original model only assumed an empirical Taylor rule to describe the behavior of the monetary authority. Obviously, as we are interested in Banxico's preference parameters we will need to add an optimizing monetary authority that minimizes a loss function.

The model consists of four agents: households, domestic firms, importing firms and the central bank. We will now describe the economic behavior of each one of them.

3.1 Households

The economy is populated by infinitely-lived households who maximize the period utility

$$U(C_t, H_t, N_t) = \frac{(C_t - H_t)^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi}, \tag{1}$$

where C_t is an index of consumption goods, N_t is the labor input and $H_t \equiv hC_{t-1}$ is an external habit stock taken as exogenous by the household.[8] Parameter h measures the degree of habit persistence. The parameters σ, $\varphi > 0$ are the inverse elasticities of intertemporal substitution and labor supply, respectively. The consumption composite index C_t is given by

$$C_t = \left[(1-\alpha)^{\frac{1}{n}} C_{H,t}^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{n}} C_{F,t}^{\frac{\eta-1}{\eta}} \right], \tag{2}$$

[7]For an extensive discussion on New Keynesian modelling and their advantages, see Galí and Gertler (2007).

[8]Past research on household consumption and asset choices has found that habits may be an essential part of household preferences. See for example Campbell and Cochrane (1999) regarding the equity premium puzzle and Fuhrer (2000) for a discussion in the context of consumption behavior.

where $\alpha \in [0,1]$ is the share of foreign goods in the domestic consumption bundle. Under this specification, $\eta > 0$ measures the elasticity of substitution between domestic and foreign goods. C_H and C_F are the typical Dixit-Stiglitz aggregates of domestic and imported goods:

$$C_{H,t} = \left[\int_0^1 C_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}} \quad ; \quad C_{F,t} = \left[\int_0^1 C_{F,t}(j)^{\frac{\varepsilon-1}{\varepsilon}} dj\right]^{\frac{\varepsilon}{\varepsilon-1}}. \tag{3}$$

Notice that similar to η, $\varepsilon > 1$ measures the elasticity of substitution between types of differentiated domestic or foreign goods (elasticity of substitution between goods within each good category H and F).

Let B_t be an Arrow security that pays out contingent on the state of the world. The stochastic discount factor is $\mathbb{E}_t Q_{t,t+1}$ and it will be inversely related to the gross return on a nominal riskless one period bond, $\mathbb{E}_t Q_{t,t+1} = R_t^{-1}$. Thus, the household solves the following Bellman equation

$$V(B_t, H_t) = \max_{C_t, N_t} \; U(C_t, H_t, N_t) + \beta \mathbb{E}_t[V(B_{t+1}, H_{t+1})] \quad \text{where} \quad \beta \in (0,1) \tag{4}$$

subject to the budget constraint

$$B_t \geq \int_0^1 \int_0^1 [P_{H,t}(i) C_{H,t}(i) + P_{F,t}(j) C_{F,t}(j)] di dj + \mathbb{E}_t Q_{t,t+1} B_{t+1} - W_t N_t, \tag{5}$$

for all $t > 0$, where B_0 is given and $W_t N_t$ is the total wage income. $P_{H,t}(i)$ and $P_{F,t}(j)$ are the prices for each differentiated home and foreign good of type $i \in [0,1]$ and $j \in [0,1]$, respectively.

The household optimally decides the expenditures across all types of domestic and foreign goods. First, we obtain the following demand functions for each differentiated good

$$C_{H_t}(i) = \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon} C_{H,t}, \qquad C_{F_t}(j) = \left(\frac{P_{F,t}(j)}{P_{F,t}}\right)^{-\varepsilon} C_{H,t} \tag{6}$$

for all $i, j \in [0,1]$, where the associated aggregate price indexes $P_{H,t}$ and $P_{F,t}$ are given by

$$P_{H,t} = \left(\int_0^1 P_{H,t}(i)^{1-\varepsilon} di\right)^{\frac{1}{1-\varepsilon}} \quad \text{and} \quad P_{F,t} = \left(\int_0^1 P_{F,t}(j)^{1-\varepsilon} dj\right)^{\frac{1}{1-\varepsilon}}. \tag{7}$$

Similarly, we can also obtain the optimal consumption demand for domestic and foreign goods, given by

$$C_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t \quad , \quad C_{F,t} = \alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} C_t \tag{8}$$

If we substitute (8) into (2), we obtain the consumer price index (CPI)

$$P_t = \left[(1-\alpha)P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta}\right]^{\frac{1}{1-\eta}}. \tag{9}$$

The next optimality condition relates labor supply to the real wage at any time t (intratemporally)

$$(C_t - H_t)^{\sigma} N_t^{\varphi} = \frac{W_t}{P_t}, \tag{10}$$

that is, the marginal rate of substitution between consumption and leisure must be equal to the marginal product of labor. As households optimize both intratemporally and intertemporally, we add the last optimality condition

$$\beta\left(\frac{C_{t+1} - H_{t+1}}{C_t - H_t}\right)^{-\sigma}\left(\frac{P_t}{P_{t+1}}\right) = Q_{t,t+1}, \tag{11}$$

which is satisfied for all dates and states $t \in \mathbb{N}$. Taking conditional expectations to (11) yields the next stochastic Euler equation

$$\beta R_t \mathbb{E}_t\left\{\left(\frac{C_{t+1} - H_{t+1}}{C_t - H_t}\right)^{-\sigma}\left(\frac{P_t}{P_{t+1}}\right)\right\} = 1. \tag{12}$$

3.2 International Risk Sharing and Relative Prices

A representative agent in the rest of the world faces the same optimization problem to the small open economy. The only difference is that the rest of the world is the limiting case of a closed economy, that is $\alpha^* \to 1$.[9]

As the optimization process is the same, firs-order conditions given by (10) and (11) also hold. Remember that the discount factor $Q_{t.t+1}$ is inversely related to the nominal riskless bond. Denoting foreign variables and parameters with an asterisk, and assuming complete

[9] As Monacelli (2005) notes, this is a world of two asymmetric countries in which one is small relative to the other. Small open economy models with incomplete markets traditionally suffer a unit-root problem. The setup used in this work overcomes this limitation.

international markets and identical global preferences, we get perfect risk sharing from (11)

$$\beta\left(\frac{C_{t+1}-H_{t+1}}{C_t-H_t}\right)^{-\sigma}\left(\frac{P_t}{P_{t+1}}\right)=Q_{t,t+1}=\beta\left(\frac{C^*_{t+1}-H^*_{t+1}}{C^*_t-H^*_t}\right)^{-\sigma}\left(\frac{P^*_t}{P^*_{t+1}}\right)\left(\frac{\tilde{e}_t}{\tilde{e}_{t+1}}\right). \tag{13}$$

where $\tilde{e_t}$ is the nominal exchange rate. Real exchange rate $\tilde{q}$ is defined by

$$\tilde{q}_t=\tilde{e}_t\frac{P^*_t}{P_t}. \tag{14}$$

I assume identical countries and no preference shocks to rest of the world. This implies that

$$C_t-hC_{t-1}=\nu^*(C^*_t-hC^*_{t-1})\tilde{q}_t^{\frac{1}{\sigma}} \tag{15}$$

where $\nu^*=1$ imposes zero net foreign asset holdings and symmetry of countries. Using a log-linear approximation[10]we can transform (15) into

$$c_t-hc_{t-1}=y^*_t-hy^*_{t-1}+\frac{1-h}{\sigma}q_t, \tag{16}$$

where $c_t:=ln(C_t/C_{SS})$, $y^*_t:=ln(Y^*_t/Y^*_{SS})$, and $q_t:=ln(\tilde{q}_t/\tilde{q}_{SS})$ denote the percentage deviation of home consumption, foreign output, and real exchange rate from their respective steady state X_{SS}. Note that if the rest of the world economy functions like a closed economy, then $y^*_t=c^*_t$.

Using (13) and (14) we can derive the uncovered interest rate parity condition

$$R_t-R^*_t\frac{\tilde{e}_t}{\tilde{e}_{t+1}}=0. \tag{17}$$

Equation (17) comes from combining efficiency conditions for an optimal portfolio of bonds by both domestic and foreign residents under a complete international asset market. Log-linearizing and taking expectations conditional on information in t, we get

$$r_t-r^*_t=\mathbb{E}_te_{t+1}-e_t \tag{18}$$

where $e_t:=ln(\tilde{e}_t/\tilde{e}_{SS})$, $r_t=R_t-1$, and $r^*_t=R^*_t-1$. We can define the terms of trade between the domestic economy and the rest of the world as $\mathcal{S}_t=\frac{P_{F,t}}{P_{H,t}}$. In other words the price of foreign

[10]Log-linear approximations are very useful in DSGE models as they allow for analytical solutions. See Campbell (1994) for a primer on log-linearization.

goods in terms of home goods. In log-linear terms we have

$$s_t = p_{F,t} - p_{H,t}. \tag{19}$$

Note that equation (19) holds independently of the degree of pass-through.

3.3 Domestic Producers

In the domestic goods market we assume a continuum of monopolistically competitive firms, indexed by $i \in [0,1]$. Following the usual convention, we assume a Calvo price-setting mechanism. We add partial inflation indexation for nonoptimizing price setters, which will allow inflation to be a partly jump variable and partly backward looking.

The firms operate a linear technology $Y_{H,t}(i) = \epsilon_{a,t} N_t(i)$ where $\epsilon_{a,t}$ is an exogenous domestic technology shock. In any period t, firms face a signal that allows a fraction $1-\theta_H$ to set prices optimally, while a fraction $0 < \theta_H < 1$ adjusts their prices according to the following indexation rule

$$P_{H,t}(i) = P_{H,t-1}(i) \left(\frac{P_{H,t-1}}{P_{H,t-2}} \right)^{\delta_H}, \tag{20}$$

where $0 \leq \delta_H \leq 1$ measures the degree of indexation to the previous period's inflation. Given that at any time t the firms with the opportunity to reset their price face the same problem, they set a common price $P'_{H,t}$. Then, we can define the evolution of the Dixit-Stiglitz aggregate price index as

$$P_{H,t} = \left[(1-\theta_H)(P'_{H,t})^{1-\varepsilon} + \theta_H \left(P_{H,t-1} \left(\frac{P_{H,t-1}}{P_{H,t-2}} \right)^{\delta_H} \right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}. \tag{21}$$

If a firm offering a product i sets its price at time t, it will face the demand

$$Y_{H,t}(i) = \left(\frac{P_{H,t}(i)}{P_{H,T}} \cdot \left(\frac{P_{H,T-1}}{P_{H,t-1}} \right)^{\delta_H} \right)^{-\varepsilon} (C_{H,t} + C^*_{H,T}) \tag{22}$$

for all t and it will take aggregate prices and consumption bundles as parametric.

Firms setting prices optimally maximize the expected present discounted value of profits:

$$\max_{P_{H,t}(i)} \mathbb{E}_t \sum_{s=0}^{\infty} Q_{t,t+s}\theta_H^s Y_{H,t+s}(i) \times \left[P_{H,t}(i) \left(\frac{P_{H,t+s-1}}{P_{H,t-1}} \right)^{\delta_H} - P_{H,t+s} MC_{H,t+s} \exp(\epsilon_{H,t+s}) \right] \quad (23)$$

subject to (22) and the technological constraint given by real marginal cost,

$$MC_{H,t+s} = \frac{W_{t+s}}{\epsilon_{a,t+s} P_{H,t+s}}. \quad (24)$$

We allow for a structural shock to real marginal cost given by $\epsilon_{H,t} \sim$ i.i.d. $(0, \sigma_H)$. This shock has the interpretation of an independent cost-push shock to domestic goods producers. From (23) we get the following first order condition characterizing domestic firms' optimal pricing

$$\mathbb{E}_t \sum_{s=0}^{\infty} \theta_H^s Q_{t,t+s} Y_{H,t+s}(i) \times \left[\tilde{P_{H,t}} \left(\frac{P_{H,t+s-1}}{P_{H,t-1}} \right)^{\delta_H} - \left(\frac{\varepsilon}{\varepsilon - 1} \right) P_{H,t+s}(i) MC_{h,t+s} \exp(\epsilon_{H,t+s}) \right] = 0. \quad (25)$$

If we log-linearize expression (25), we get the following Phillips curve for domestic goods inflation[11]

$$\pi_{H,t} - \delta_H \pi_{H,t-1} = \beta(\mathbb{E}_t \pi_{H,t+1}) + \lambda_H (mc_{H,t} + \epsilon_{H,t}), \quad (26)$$

where $\lambda_H = (1 - \beta\theta_H)(1 - \theta_H)\theta_H^{-1}$ and

$$mc_{H,t} = \varphi y_t - (1 + \varphi)\epsilon_{a,t} + \alpha s_t + \frac{\sigma}{1-h}(y_t^* - h y_{t-1}^*) + q_t + \epsilon_{c,t}.$$

3.4 Import Retail Firms

As there are no differences in global preferences, foreign firms charge the same price inside and outside of their country. Thus, retail firms import foreign goods for which the law of one price holds at the docks. However, import retail firms act as monopolistically competitively resellers, so they determine the domestic currency price of the imported good. Because there is difference between the price in international markets and the domestic retail price, a violation of the law

[11] The procedure for obtaining (26) is detailed in Appendix A.1 of Kam, Lees and Liu (2009).

of one price arises. We define the law of one price gap in log-linear terms as

$$\psi_{F,t} = e_t + p_t^* - p_{F,t}. \tag{27}$$

Retail firms also follow a Calvo-style pricing allowing for indexation to past inflation. The evolution of the imports price index is given by

$$P_{F,t} = \left[(1-\theta_F)(P'_{F,t})^{1-\varepsilon} + \theta_F \left(P_{F,t-1} \left(\frac{P_{F,t-1}}{P_{F,t-2}} \right)^{\delta_F} \right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}, \tag{28}$$

where $1-\theta_F$ is the fraction of the firms that set prices optimally at time t and θ_F is the fraction of firms that adjust prices according to the indexation rule in (20). The demand curve faced by firm j in time $t+s$ is

$$Y_{F,t+s}(j) = \left[\frac{P_{F,t}(j)}{P_{F,t+s}} \left(\frac{P_{F,t+s-1}}{P_{F,t-1}} \right)^{\delta_F} \right]. \tag{29}$$

The intertemporal optimization problem for the import retail firm is

$$\max_{P_{F,t}(j)} \mathbb{E}_t \sum_{s=0}^{\infty} Q_{t,t+s} \theta_F^s Y_{F,t+s}(j) \times \left[P_{F,t}(j) \left(\frac{P_{F,t+s-1}}{P_{F,t-1}} \right)^{\delta_F} - \tilde{e}_{t+s} P^*_{F,t+s}(j) \exp(\epsilon_{F,t+s}) \right] \tag{30}$$

subject to (29) for $t, s = 0, 1, \ldots$. We introduce another structural shock to marginal cost given by $\epsilon_{F,t} \sim$ i.i.d. $(0, \sigma_F)$. Similar to $\epsilon_{H,t}$ we can interpret this shcok as an independent cost-push shock to import retailers. The next first order condition follows from (30)

$$\mathbb{E}_t \sum_{s=0}^{\infty} \theta_F^s Q_{t,t+s} Y_{F,t+s}(j) \times \left[\tilde{P}_{F,t} \left(\frac{P_{F,t+s-1}}{P_{F,t-1}} \right)^{\delta_F} - \left(\frac{\varepsilon}{\varepsilon - 1} \right) \tilde{e}_{t+s} P_{F,t+s}(j) \exp(\epsilon_{F,t+s}) \right] = 0. \tag{31}$$

Log-linearizing (31) around its steady state[12] yields

$$\pi_{F,t} = \beta \mathbb{E}_t(\pi_{F,t+1} - \delta_F \pi_{F,t}) + \delta_F \pi_{F,t-1} + \lambda_F(\psi_{F,t} + \epsilon_{F,t}) \tag{32}$$

where $\pi_{F,t} := ln(\frac{P_{F,t}}{P_{F,t-1}})$ and $\lambda_F = (1-\beta\theta_F)(1-\theta_F)\theta_F^{-1}$.

[12] A detailed procedure for obtaining (32) is detailed in Appendix A.2 of Kam, Lees and Liu (2009).

3.5 Market Clearing Conditions

First, we are going to derive a relationship between the terms of trade, the real exchange rate, and the law of one price gap. If we log-linearize real exchange rate (14) we have

$$q_t = e_t + p_t^* - p_t. \tag{33}$$

Using law of one price gap definition (27) and the terms of trade expression (19), we can rewrite (33) as

$$q = \psi_{F,t} + p_{F,t} - p_t \quad \approx \quad \psi_{F,t} - (1-\alpha)(p_{F,t} - p_{H,t}) = \psi_{F,t} - (1-\alpha)s_t. \tag{34}$$

As we said before, the rest of the world works as a closed economy so that $y_t^* = c_t^*$ for all t. The goods market clearing condition in the domestic economy requires that domestic output equals domestic and foreign demand for local goods

$$y_t = c_{H,t} + c_{H,t}^*. \tag{35}$$

Using log-linear approximation in the demand for home and foreign goods we have that $c_{H,t} = (1-\alpha)[\alpha\eta s_t + c_t]$ and $c_{H,t}^* = \alpha[\eta(s_t\psi_{F,t}) + y_t^*]$. Substituting on (35) we get

$$y_t = (2-\alpha)\alpha\eta s_t + (1-\alpha)c_t + \alpha\eta\psi_{F,t} + \alpha y_t^*. \tag{36}$$

3.6 Log-linear model

This section summarizes the log-linearized equilibrium conditions of the model. We start with the *consumption Euler equation.* This was obtained by log-linearizing (11) and taking conditional expectations:

$$c_t - hc_{t-1} = \mathbb{E}_t(c_{t+1} - hc_t) - \frac{1-h}{\sigma}(r_t - \mathbb{E}_t\pi_t + 1). \tag{37}$$

Domestic goods inflation is given by (26) and substituting out $mc_{H,t}$:

$$\begin{gathered}\pi_{H,t} = \beta\mathbb{E}_t(\pi_{H,t+1} - \delta_H\pi_{H,t}) + \delta_H\pi_{H,t-1} + \\ \lambda_H\left[\varphi y_t - (1+\varphi)\epsilon_{a,t} + \alpha s_t + \frac{\sigma}{1-h}(c_t - hc_{t-1})\right] + \lambda_H\epsilon_{H,t}.\end{gathered} \tag{38}$$

Imported goods inflation is given by (32) and substituting out the law of one price gap $\psi_{F,t}$ with (34)

$$\pi_{F,t} = \beta \mathbb{E}_t(\pi_{F,t+1} - \delta_F \pi_{F,t}) + \delta_F \pi_{F,t-1} + \lambda_F[q_t - (1-\alpha)s_t] + \lambda_F \epsilon_{F,t}. \tag{39}$$

The *real interest rate parity condition* is obtained by first-differencing (33), taking conditional expectations, and combining with (17)

$$\mathbb{E}_t(q_{t+1} - q_t) = (r_t - \mathbb{E}_t \pi_{t+1}) - (r_t^* - \mathbb{E}_t \pi_t^* + 1) + \epsilon_{q,t}. \tag{40}$$

The *terms of trade equation* is obtained by first-differencing (19)

$$s_t - s_{t-1} = \pi_{F,t} - \pi_{H,t} + \epsilon_{s,t}. \tag{41}$$

Next, the *goods market clearing condition* is obtained by combining goods market clearing (36) and the law of one price gap (27)

$$y_t = (1-\alpha)c_t + \alpha\eta q_t + \alpha\eta s_t + \alpha y_t^*. \tag{42}$$

CPI inflation comes from log-linearizing consumer price index (9) and taking first differences yields CPI inflation

$$\pi_t = (1-\alpha)\pi_{H,t} + \alpha \pi_{F,t}. \tag{43}$$

We assume that the *exogeneous shocks* to terms-of-trade, technology, and real-interest-parity shocks follow an AR(1) process

$$\begin{aligned} \epsilon_s &= \rho_s \epsilon_{s,t-1} + v_{s,t}, \quad \text{where } v_s \sim \text{i.i.d.}(0, \sigma_s^2) \\ \epsilon_a &= \rho_a \epsilon_{a,t-1} + v_{a,t}, \quad \text{where } v_a \sim \text{i.i.d.}(0, \sigma_a^2) \\ \epsilon_q &= \rho_q \epsilon_{q,t-1} + v_{q,t}, \quad \text{where } v_q \sim \text{i.i.d.}(0, \sigma_q^2). \end{aligned} \tag{44}$$

As was mentioned, the marginal cost shocks in the home goods and import retailers profit functions are $\epsilon_H \sim$ i.i.d.(0,σ_H) and $\epsilon_F \sim$ i.i.d. (0,σ_F) respectively. Following Kam, Lees, and Liu (2009), we also assume that *foreign country variables* $\{\pi^*, y^*, r^*\}$ follow uncorrelated AR(1) processes

$$\begin{pmatrix} \pi_t^* \\ y_t^* \\ r_t^* \end{pmatrix} = \begin{pmatrix} a_1 & 0 & 0 \\ 0 & b_2 & 0 \\ 0 & 0 & c_3 \end{pmatrix} \begin{pmatrix} \pi_{t-1}^* \\ y_{t-1}^* \\ r_{t-1}^* \end{pmatrix} + \begin{pmatrix} \sigma_{\pi^*} & 0 & 0 \\ 0 & \sigma_{y^*} & 0 \\ 0 & 0 & \sigma_{r^*} \end{pmatrix} \begin{pmatrix} v_{\pi^*,t} \\ v_{y^*,t} \\ v_{r^*,t} \end{pmatrix} \tag{45}$$

where $v_{\pi^*,t}, v_{y^*,t}, v_{r^*,t} \sim N(0, I_3)$. This simplification helps to reduce the number of parameters to estimate, resulting in a more parsimonious model.[13]

Therefore, the domestic economy is summarized by equations (37) through (43) for the endogenous variables $\{c_t,\ y_t,\ q_t,\ s_t,\ r_t,\ \pi_t,\ \pi_{H,t},\ \pi_{F,t}\}$. We add the exogenous disturbances $\{\epsilon_{s,t},\ \epsilon_{a,t},\ \epsilon_{q,t}\}$ described by (44), the marginal cost shocks $\{\epsilon_{H,t},\ \epsilon_{F,t}\ \}$, and the foreign processes $\{\pi_t^*,\ y_t^*,\ r_t^*\}$ given by (45). All these combined constitute a linear rational expectations model. The only thing missing is to model how the central bank behaves, which is explained in the next subsection.

3.7 Central Bank Optimization

Following the literature, and in particular Kam, Lees, and Liu (2009), I assume that the central bank minimizes the next period linear-quadratic loss function

$$L(\tilde{\pi}_t, y_t, q_t, r_t - r_{t-1}) = \frac{1}{2}\left[\tilde{\pi}_t^2 + \mu_y y_t^2 + \mu_q q_t^2 + \mu_r (r_t - r_{t-1})^2\right] \tag{46}$$

where $\tilde{\pi}_t \equiv \sum_{i=0}^{3} \pi_{t-i}/4$ is the annual inflation rate (in a quarterly model). Equation (46) is a very useful representation of the policy objective for various reason. From a computational point of view, there exist many tools to analyse linear-quadratic stochastic dynamic optimization problem (e.g. Dennis, 2007). As Svensson (1999) describes, equation (46) properly reflects the ideas that motivate IT. Finally, this type of policy function is used extensively in the monetary policy rules literature (e.g. Taylor, 1999, among many others).

The parameters I am interested are $\mu_y, \mu_q, \mu_r \in [0, +\infty)$, representing the relative importance that the central bank assigns to output stabilization, real exchange rate stabilization and interest rate smoothing, respectively. For comparison purposes, the weight assigned to annual inflation is normalized to one. Carstens and Werner (2000) explain that since 1996, Banxico's

[13] There is not a usual convention in the literature of how to specify the foreign economy. For example, Justiniano and Preston (2010) use a vector autorregressive processes of order two and Monacelli (2005) specifies the foreign economy as the closed-economy version of his small open economy model.

monetary programs have always included the possibility for the central bank to adjust its stance on monetary policy. This element represents the use of discretion in monetary policy, so, naturally, I will assume that monetary policy is performed under discretion[14] in this model.[15] This is also consistent with the solution algorithm of Dennis (2007) employed in Kam, Lees, and Liu (2009).

In addition to the common specification with only inflation and output, I include a weight on exchange rate stabilization. Svensson (2000) mentions that the real exchange rate plays a prominent role in the transmission mechanism of monetary policy in a small open economy. In addition, foreign disturbances such as abrupt changes in foreign inflation can be transmitted through the exchange rate channel.

Following the literature, I also include a nonnegative weight on the interest rate smoothing. This component is meant to capture the observed inertial behavior in the interest rates. Usually, monetary policy gradualism or policy inertia is reflected in this term (e.g. Rudebusch, 2006). Nonetheless, as Ilbas (2012) explains, there can be many reasons behind its inclusion. Sack and Wieland (1999) argue that interest rate smoothing could arise from three characteristics of the policymaking environment: forward-looking behavior by market participants, measurement error associated with key macroeconomic variables, and uncertainty regarding relevant structural parameters.

Note that this loss function encompasses different variants of inflation targeting. "Strict" CPI-inflation targeting would correspond to the case where $\mu_y = \mu_q = \mu_r = 0$. "Flexible" IT would allow for other positive weights.

The central bank's goal is to minimize (46) subject to structural economic equations (37)-(45), under discretion. Optimal monetary policy must be time consistent. For the solution, I restrict time consistency to a class of dynamic games characterized by Markov-perfect equilibrium payoffs and strategies. The Markov-perfect equilibria problem is described in detail on Appendix A. Specifically, I use the algorithm proposed by Dennis (2006). Intuitively, the solution considers the central bank contemporaneous decisions as a Stackelberg leader, whereas the private agents and the future Central Bank's actions are regarded as Stackelberg followers.

[14]When solving under discretion, the central bank treats the problem as one of sequential optimization. It makes whatever decision is optimal each period without committing itself to any future actions. When solving under commitment, the central bank credibly commits to a policy plan.

[15]In the current literature, there is not a common agreement on modelling monetary policy under discretion or commitment. As it is more in line with "flexible" IT, the great majority assume a discretionary optimization, but there are other works like Ilbas (2010, 2012) and Salemi (2006) where commitment is used.

The resulting solution is an optimal interest rate rule $r_t(\varepsilon_t, z_{t-1})$. I add a noise term $\epsilon_{r,t} \sim N(0, \sigma_r^2)$ to this interest rate rule that will capture the inability of the central bank to control the interest rate perfectly.

4 Estimation

4.1 Data

On the eve of the Mexican crisis, with the intention of tackling inflation, Banxico tried to reach an inflation target in 1995 and 1996, failing completely in both years.[16] Although inflation targets were given, as Wynne and Skelton (2011) describe, the monetary policy in that period cannot be considered as full IT. More correctly, its anchor was a monetary growth target, defined as a growth ceiling on net domestic credit. The actual strategy was to limit the expansion of domestic credit and increase the international reserves.

It was not until 1998 that the monetary policy framework began a real transition toward an explicit full-fledged IT regime. Banxico reinforced the role of the inflation target and began raising policy transparency. The monetary base became less relevant and the inflation target more important in the conduct of policy. In 1999, Banxico began to announce annual inflation targets, aiming to converge to the levels of inflation of Mexico's primary trading partners. Finally, in 2000 Banxico started the publication of its quarterly inflation report, which analyses inflation prospects, the conduct of monetary policy, and the balance of risks for future inflation.

Although Banxico officially adopted IT in 2001, I use quarterly data over the period 2000:1 to 2013:4. In 2000, almost all of the elements needed in an IT regime were used in Mexico. In fact, Schmidt et al. (2002) consider that the IT regime started in Mexico in 1999, when Banxico defined a series of annual inflation targets.

As I have nine structural shocks in the model $\{\epsilon_s, \epsilon_a, \epsilon_q, v_{\pi^*},\ v_{y^*},\ v_{r^*}, \epsilon_H, \epsilon_F, \epsilon_r\}$, I will need nine observable time series to avoid stochastic singularity. I use a dataset containing the following nine variables: imported goods inflation denominated in domestic currency ($\pi_{F,t}$), real exchange rate (MXN/US) (q_t), the terms of trade (s_t), real domestic GDP (y_t), domestic CPI inflation (π_t), nominal interest rate (r_t), US CPI inflation (π_t^*), US real output (y_t^*), and the US federal funds rate (π_t^*).

All the Mexican series were downloaded from Banxico's website. US series were obtained

[16]The inflation target in 1995 was 19%, whereas actual inflation rose to 52%. In 1996 Banxico failed again the target of 10%, obtaining an actual inflation of 27.7%.

from the FRED system from the Federal Reserve Bank of St. Louis. Inflation is calculated as the log difference of the CPI index. Both inflation and real GDP were seasonally corrected for both countries. Following Smets and Wouters (2007), real GDP is expressed in per capita by dividing over the population over 15. Real exchange rate was obtained by multiplying the nominal exchange rate by the price index ratio between US and Mexico. The output gap y_t is constructed as the difference between the seasonally adjusted real GDP and the potential output obtained through the Hodrick-Prescott filter. In Figure 1 we show the original series. Note the great impact of the 2008 crisis.

4.2 Methodology

The adoption of a Bayesian statistical approach in a DSGE context is particularly attractive. From a Bayesian perspective we interpret parameters as random variables (DeJong and Dave, 2007). We can then make some statements about the parametrization conditioned on three factors: the theoretical structure of the model, the observed data, and a prior distribution specified for the parameters.[17]

In order to derive the posterior distributions for the parameters of interest, I use the Metropolis Markov chain Monte Carlo (MCMC) method. The full estimation algorithm is detailed in Appendix B.[18] The algorithm is based on 250,000 MCMC draws and a 2,500 Kalman filter iterations (see Appendix B). I discard 20% of the sample to remove initial condition effects.

As the posterior density distribution is derived by combining the prior distribution with the likelihood function, the selection of prior distributions for each parameter plays a fundamental role in the estimation stage. Following many of the proposed distributions in Kam, Lees and Liu (2009), I present the priors used in this paper in Table 1. Note that in the selection of the prior distributions I conform to certain conventions, mainly taking into account the interval of variation of each parameter. Specifically, I use the beta distribution for parameters in the interval [0,1], inverse gamma distribution for those in the interval $[0, \infty)$, and the gamma distribution for the rest.

Notice that we assume that the prior distribution for the policy parameters μ_y, μ_q and μ_r is exactly the same. Any resulting difference in the posterior parameters distribution will therefore be due to data.

[17]For a detailed discussion on Bayesian methods and their application in DSGE models, look at Smets and Wouters (2003), Schorfheide (2006), and An and Schorfheide (2007).

[18]I wish to express my gratitude to Dr. Timothy Kam, who kindly sent me his MATLAB codes.

4.3 Results

Figure 2 shows both the assumed prior and the estimated posterior distributions for each parameter. Overall, posterior distributions are very different to the prior assumptions. The first step in our analysis is to check if the estimated parameters have converged to a stable distribution.

In Table 2 I report the mean estimates, the 95% confidence intervals, and then some diagnostic tests for convergence. NSE in the eighth column stands for numerical standard errors, as proposed by Geweke (1992). The NSE is an approximation to the true posterior standard error. Although the number by itself doesn't tells us very much about convergence, the p-value reported in column nine does. This test, commonly known as Geweke chi-squared convergence test, compares the mean of the first 20% of the sample of the draws versus the mean of the last 50% of the sample. If the Markov chain of draws has converged to a stable distribution, we would expect the means from these two splits to be statistically equal. The null hypothesis of the test is that the means are equal. Thus, a low p-value will show some evidence of problems in convergence. From Table 2 we see that there are five parameters that fail the test at a 5% level: $\phi, a_1, \rho_s, \sigma_H, \sigma_F$, and σ_{r^*}. Except for σ_{r^*}, all of these parameters also fail the test at a 1% level.

In the last column I show the univariate shrink factor developed by Gelman and Rubin (1992) and retaken by Brooks and Gelman (1998). The basic idea of this test is to run the chain two or more times from a widely-dispersed starting point and see if the chain always converge to the same place. Commonly, a value below 1.1 is considered as little evidence of dispersion. This test is particularly useful in our case. If we check Figure 2, we can easily note that many parameters present bimodal or even multimodal distributions. If we initialize the chain near one of this modes, it may never find the other one.

The test shows that evidence of dispersion for six parameters: $\sigma, c_3, \rho_s, \mu_r, \sigma_H$ and σ_F. Only σ_F has a shrink factor above 1.2, consequence of having two modes of almost the same height in its distribution. Despite this results, we can say that overall every parameter converges to an invariant distribution.

The second step of our analysis is to check if the estimated structural parameters are economically plausible. First, we note that the degree of consumption habit persistence $\hat{h} = 0.93$ is incredibly high, very close to one. This is consistent with other literature like García-Cicco (2008) who finds a value of 0.83 for Mexico. Still, consumption is very sensitive to interest rate changes, represented by the coefficient of relative risk aversion $\hat{\sigma} = 0.77$. We also note that

$\hat{\eta} = 0.31$, which means that there is lower elasticity of substitution of consumption between home and foreign goods in the model. This also means that Mexico's output gap won't be so responsive to terms of trade movements. Finally, we take a look at $\hat{\delta}_H$ and $\hat{\delta}_F$. This parameters represent the backward-lookingness of the price of domesitc and imported goods, respectively. They are pretty low compared to the initial prior mean, especially for the imported goods sector. The parameter values are generally consistent with the values reported by Kam, Lees and Liu (2009) for Australia, Canada and New Zealand.

Policy Parameters

As I stated before, we are interested in the parameters associated with the Central Bank loss function. The estimated values for μ_q, μ_y, and μ_r are 0.004, 0.47, and 0.67, respectively. As shown by these results, Banxico gives a greater value to inflation stabilization (it is our reference value, weight equal to 1). Inflation stabilization is followed in importance by interest rate smoothing ($\mu_r = 0.67$), output stabilization ($\mu_y = 0.47$) and finally exchange rate stabilization ($\mu_r = 0.004$).

Although we can affirm that Banxico has not behaved as a "strict" inflation targeter, what else can we say about this preference ordering? Is this kind of behavior normal?

If we do a small cross-country comparison among other inflation targeters, we note that our results are similar to the ones obtained by Kam, Lees and Liu (2009) (Australia, Canada, and New Zealand) and Palma and Portugal (2014) for Brazil.[19] You can see this in Table 3. Not surprisingly, inflation targeters behave as their name implies: they target inflation. Mexico is no exception.

Relative to the weight assigned to inflation, the next more important target for Banxico is interest rate smoothing. Canada and New Zealand assign a higher weight to interest rate smoothing than Mexico. As we have described before, interest rate smoothing has many possible sources. Policymakers may be concerned about to much financial volatility. This can be particular to interest rates as there can be maturity mis-matches between banks' assets and liabilities. Also, even if the policy instrument for central banks is the short term interest rate, monetary policy's influence comes through long-term interest rates. Persistent movements in short-term interest rates are required to generate the necessary movements in long-term rates.

[19]Strictly, to affirm that these central banks behave similarly, we would need to compare the joint posterior distribution of their policy preferences parameters, not only the mean.

This result is consistent with results in other studies. For example, Dennis (2004) shows that, to describe US data correctly, a much larger weight has to be attached to interest rate smoothing.[20]

In terms of output stabilization, Banxico assigns a higher a relative weight of 0.47. We could say that Banxico considers output to be half as important than inflation similar to Australia and Brazil. For Canada and New Zealand, the output gap is even less important. There has been a long discussion in the literature if central banks should not only be targeting inflation, but also output. For example, Fischer (1996) argues that central bankers downplay the possibilities of counter-cyclical policies in the short-run due to political issues. He adds that under inflation targeting, long-run price stability should be the primary goal, with the promotion of full employment and growth being permitted as secondary goals. This seems to be the case for Mexico and many other inflation targeters.[21]

Lastly, the weight assigned to exchange rate is very close to zero, and has the lowest parameter of the group. This result contrasts with the much higher value that Brazil, a Latinamerican fellow, assigns. This result goes in line with the conclusions of Bergin et al. (2007) model. They find that the benefits of pursuing exchange rate stabilization are quite small for small open economies.

5 Conclusions

In this work I estimate the parameters of Mexican monetary policy in an optimizing time-consistent discretionary framework since the instalment of the IT regime. Using Kam, Lees, and Liu (2009) model as the benchmark, I aim to uncover what does Banxico care about. I focus on four goals of monetary policy: inflation stabilization, minimizing deviations of output gap, interest rate smoothing and reducing exchange rate volatility. Results obtained by Bayesian estimation indicate that the primary concern for Banxico has indeed been inflation, as stated by the Mexican laws. However, other (implicit) goals of monetary policy have been important too, in the following order of relative weights: interest rate stability, output gap difference, and

[20] At first sight, the results might not be comparable with the US, as monetary policy does not work under an IT regime and Federal Reserve has a dual mandate. Nonetheless, Bernanke and Mishkin (1997) argue that the Federal Reserve is an implicit inflation targeter.

[21] Also, a positive weight on output in the central bank's loss function does not necessarily result in a trade-off. When dealing with monetary policy, it is commonly accepted that there is a short-term trade-off in output and inflation. Svensson (1997) shows that a positive weight on output stabilization can translate into a more gradualist policy. With a zero weight on output stabilization, the central bank should set the instrument such that the inflation forecast for the control lag always equals the inflation target. With a positive weight, the inflation forecast should be adjusted gradually towards the inflation target, at a slower rate the larger the weight.

finally exchange rate stabilization. This results are compatible with a "flexible" IT regime. A comparison between other small open economies with IT regimes reveals that Banxico's preferences are 'normal'. That is, Mexican preference parameters fall in-between the parameter ranges of these countries. The results appear to be robust, though there appears to be some convergence issues for some parameters.

This work can be improved along various dimensions. The reported results are conditional on the central bank's loss function specification and data. For example, Ilbas (2010) uses a loss function that includes an additional wage-inflation component. It could also be possible that preferences were not constant over this period. Persons, and not the institution, could determine the preferences of the central bank. It would be interesting to study separate periods, Guillermo Ortiz era and Agustín Carstens era, and compare if the policy parameters are similar.

Appendix A. Dennis (2007) Optimal time-consistent monetary policy

Define $W(\varepsilon_t, z_{t-1})$ as the value function of the central bank's optimal action at time t given state $z_{t-1} := \{c_{t-1},\ y^*_{t-1},\ \pi_{H,t-1},\ \pi_{F,t-1}\}$ and $\epsilon_t := (\pi^*_t,\ y^*_t,\ r^*_t,\ \{\varepsilon_{j,t}\})$, for $j = s, a, H, F, q$. A strategy of the central bank is a sequence of policy functions $\{r_t(\varepsilon_t, z_{t-1})\}_{t=0}^{\infty}$ and the private sector's collective strategy would be the sequence of allocation and pricing functions $\{c_t, \pi_{h,t}, \pi_{F,t}, q_t, s_t, y_t\}_{t=0}^{\infty}$.

In principle, we characterize our Markov-perfect equilibrium as if it were supported by central bank strategies that involve picking a sequence of all pricing and allocation functions, and private sector strategies then would be to pick expectations of such future outcomes under the central bank strategy which are consistent with the equilibrium definition. More precisely, we define an equilibrium under time-consistent optimal monetary policy as follows.

Definition 1. *Linear-quadratic Markov-perfect equilibrium (LQ-MPE). A LQ-MPE in this economy is a sequence of allocation and pricing functions,*

$$\{u_t(\varepsilon_t, z_{t-1})\}_{t=0}^{\infty} := \{c_t, \pi_{H,t}, \pi_{F,t}, q_t, r_t, s_t, y_t\}$$

that satisfies:

1. *The central bank's Bellman equation,*

$$W(\epsilon_t, z_{t-1}) = \min_{u_t} L(\tilde{\pi}_t, y_t, q_t, r_t - r_{t-1}) + \beta \mathbb{E}_t W(\epsilon_{t1}, z_t) \tag{47}$$

   subject to (37)-(43).

2. *Private sector competitive equilibrium conditions (37)-(43) with conditional expectations consistent with the solution to the problem* (47).

3. *Given the exogenous stochastic processes* (44) *and* (45).

Appendix B. Kam, Lees, and Liu (2009) Pseudo-code for MCMC procedure

Algorithm. The RW-Metropolis algorithm for a linear rational expectations model:

1. Begin with an initial prior $\theta_0 \in \Theta$ and its corresponding prior density $p(\theta_0|M)$ for model M.

2. For each candidate Θ, the linear rational expectations system including the optimal monetary policy problem is solved to obtain an affine solution, $\{\mathbf{A}(\Theta), \mathbf{C}(\Theta)\}$, in terms of the endogenous state variables y_t and the central-bank policy decision variables, x_t (which is just the scalar r_t in our case)

$$\xi_{t+1} = \mathbf{A}(\Theta)\xi_t + \mathbf{C}(\Theta)\epsilon_{t+1} \tag{48}$$

where $\xi_t := (y_t, x_t)$. We can map some of the variables in ξ_t to a vector of observable variables, y_t^0 using an *observation equation*

$$y_t^0 = \mathbf{G}\xi_t. \tag{49}$$

3. For each $n = 0, 1, \ldots, N$, use (48)-(49), the given data set $y = \{y_t^0\}_{t=0}^T$ and θ_n to compute the model likelihood $L(\theta_n|y, M)$ using a Kalman filter. Then calculate the associated posterior density, $p(\theta_n|y, M) = \frac{p(\theta_n|M)L(\theta_n|y,M)}{\int_\Theta p(\theta_n|M)L(\theta_n|y,M)d\mu(\theta_n)}$.

4. Generate a new candidate draw using a random walk model: $\theta_{n+1} = \theta_n + z_{n+1}$, where we assume $z_{n+1} \sim N(0, s\Sigma)$, and $s > 0$ is a scalar factor for scaling the size of the jump in the draws. Compute the associated posterior density, $p(\theta_{n+1}|y, M)$ by repeating step 3, for θ_{n+1}.

5. Compute the acceptance probability, $\alpha(\theta_n, \theta_{n+1}|y) := \min\{\frac{p(\theta_{n+1}|y,M)}{p(\theta_n|y,M)}, 1\}$.

6. Repeat steps 3–4 for N sufficiently large to ensure that the sequence $\theta_{n\,n=0}^{\;N}$ is drawn from an ergodic distribution, π.

7. Under some sufficient conditions, we can apply the ergodic theorem of an irreducible Markov chain and approximate the posterior expected value of a (bounded) function of interest, $f(\theta)$ using the sample mean of the functions, $N^{-1}\sum_n^N f(\theta_n)$.

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6 Figures and Tables

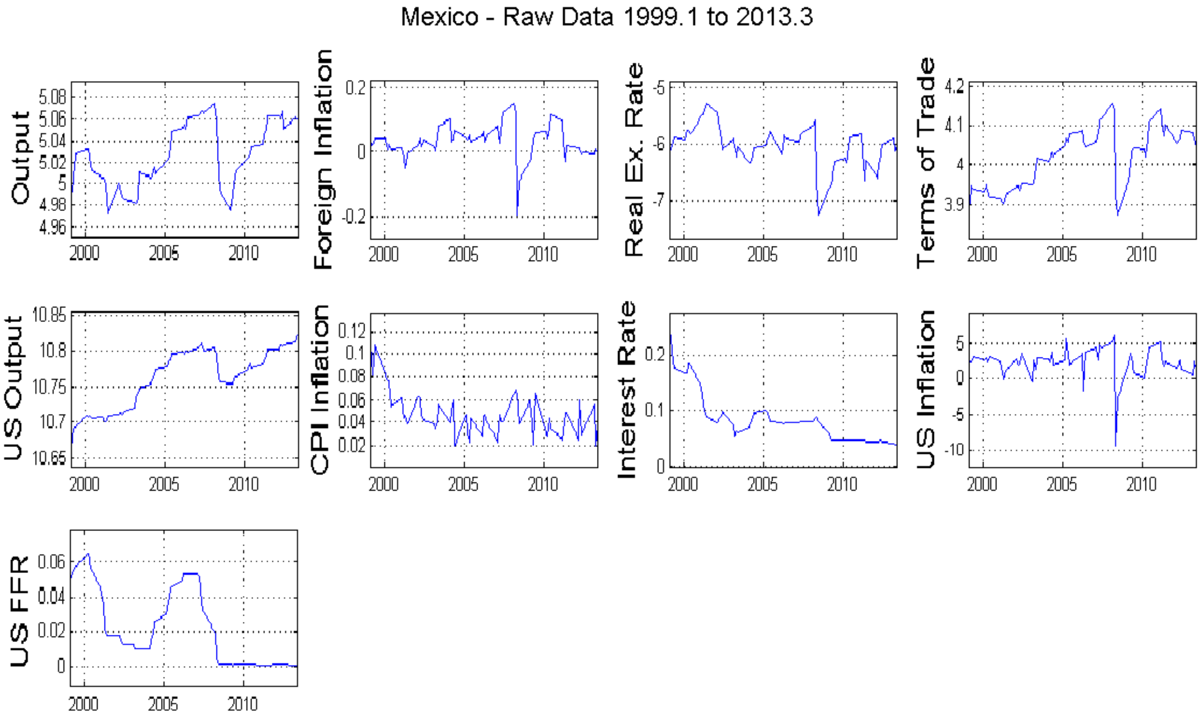

Figure 1: Raw data

Table 1: Parameter Despcription and Prior Selection

Parameter	Definition	Prior Distribution	Domain
β	Intertemporal discount rate	0.99	(0,1)
α	Economic openness	0.45	(0,1)
h	Habit persistence parameter	Beta(0.6, 0.2)	(0,1)
σ	Coefficient of relative risk aversion	Gamma (1, 0.5)	$\mathbb{R}_+$
ϕ	Inverse of the elasticity of labor supply	N(1.5, 0.25)	$\mathbb{R}_+$
η	Elasticity of substitution between domestic and imported goods	Gamma(1, 0.25)	$\mathbb{R}_+$
δ_H	Backward-looking parameter of the price of domestic goods	Beta(0.7, 0.2)	(0,1)
δ_F	Backward-looking parameter of the price of imported goods	Beta(0.7, 0.2)	(0,1)
θ_H	Fraction of non-optimizing producers in the domestic economy	Beta(0.5, 0.2)	(0,1)
θ_F	Fraction of non-optimizing importers	Beta(0.5, 0.2)	(0,1)
a_1	Parameter AR(1) of foreign inflation	Beta(0.5, 0.1)	(0,1)
b_2	Parameter AR(1) of external output	Beta(0.5, 0.1)	(0,1)
c_3	Parameter AR(1) of foreign interest rate	Beta(0.5, 0.1)	(0,1)
ρ_a	Technological inertia	Beta(0.5, 0.1)	(0,1)
ρ_q	Inertial effect of exchange rate shock	Beta(0.9, 0.1)	(0,1)
ρ_s	Inertial effect of terms of trade shock	Beta(0.25, 0.1)	(0,1)
μ_q	Preference for real exchange rate stabilization[a]	Gamma(0.5,0.09)	$\mathbb{R}_+$
μ_y	Preference for output stabilization[a]	Gamma(0.5,0.09)	$\mathbb{R}_+$
μ_r	Preference for interest rate smoothing[a]	Gamma(0.5,0.09)	$\mathbb{R}_+$
σ_H	Standard deviation of the "cost-push" shock	Inv. Gamma(2.67, 2)	$\mathbb{R}_+$
σ_F	Standard deviation of the technology shock	Inv. Gamma(2.67, 2)	$\mathbb{R}_+$
σ_a	Standard deviation of the technology shock	Inv. Gamma(2.67, 2)	$\mathbb{R}_+$
σ_q	Standard deviation of the exchange rate shock	Inv. Gamma(2.67, 2)	$\mathbb{R}_+$
σ_s	Standard deviation of the terms of trade	Inv. Gamma(1.19, 2)	$\mathbb{R}_+$
σ_{π^*}	Standard deviation of foreign inflation	Inv. Gamma(1.19, 2)	$\mathbb{R}_+$
σ_{y^*}	Standard deviation of external output	Inv. Gamma(1.19, 2)	$\mathbb{R}_+$
σ_{r^*}	Standard deviation of foreign interest rate	Inv. Gamma(1.19, 2)	$\mathbb{R}_+$
σ_r	Standard deviation of domestic interest rate	Inv. Gamma(1, 0.4)	$\mathbb{R}_+$

[a] Relative to inflation.

Table 2: Posterior Parameters and Convergence Diagnostic

	Prior mean	**2.5%**	**97.5%**	**Posterior mean**	**2.5%**	**97.5%**	NSE	p-value	B-G
h	0.60	0.20	0.93	0.93	0.88	0.99	0.0048	0.7531	1.0002
σ	1.00	0.27	2.19	0.77	0.36	1.16	0.0393	0.5695	1.1027
ϕ	1.50	1.01	1.99	1.66	1.10	2.28	0.0048	0.0094	1.0950
η	1.00	0.27	2.19	0.31	0.06	0.52	0.0192	0.7642	1.0091
δ_H	0.70	0.25	0.98	0.24	0.08	0.43	0.0103	0.1701	1.0003
δ_F	0.70	0.25	0.98	0.04	0.01	0.09	0.0014	0.4504	1.0001
θ_H	0.50	0.13	0.87	0.80	0.73	0.96	0.0108	0.3203	1.0430
θ_F	0.50	0.13	0.87	0.73	0.63	0.99	0.0181	0.3547	1.0387
a_1	0.50	0.19	0.96	0.26	0.11	0.40	0.0058	0.0315	1.0158
b_2	0.50	0.19	0.96	0.74	0.59	0.84	0.0067	0.1576	1.0103
c_3	0.50	0.19	0.96	0.85	0.49	0.98	0.0225	0.0564	1.1066
ρ_a	0.50	0.13	0.87	0.81	0.74	0.86	0.0052	0.4427	1.0692
ρ_q	0.90	0.23	1.00	0.70	0.57	0.88	0.0112	0.1578	1.0777
ρ_s	0.25	0.01	0.73	0.82	0.71	0.90	0.0048	0.0018	1.1279
μ_q	0.50	0.09	1.23	0.004	4.95×10^{-5}	0.014	0.0003	0.4555	1.0007
μ_y	0.50	0.09	1.24	0.47	0.17	0.83	0.0296	0.1794	1.0554
μ_r	0.50	0.10	1.24	0.67	0.32	1.05	0.0354	0.1494	1.1398
σ_H	2.67	0.92	7.36	1.12	0.61	1.80	0.0349	0.0037	1.1033
σ_F	2.66	0.91	7.34	3.55	0.54	6.63	0.3521	0.000	1.7430
σ_a	1.19	0.52	2.65	5.67	3.52	7.17	0.1601	0.1098	1.0250
σ_q	0.53	0.32	0.87	0.97	0.56	2.44	0.0975	0.1143	1.0862
σ_s	1.19	0.52	2.64	5.54	4.52	6.58	0.0563	0.0746	1.0765
$\sigma_{\pi*}$	1.19	0.52	2.65	0.42	0.34	0.50	0.0020	0.3106	1.0006
σ_{y*}	1.19	0.52	2.65	0.57	0.42	0.78	0.0142	0.0586	1.0921
σ_{r*}	1.19	0.52	2.65	0.21	0.14	0.26	0.0038	0.0296	1.0681
σ_r	1.19	0.52	2.64	0.36	0.17	0.47	0.0094	0.2248	1.0183

P-value is calculated with an 8% tapering.

Table 3: Cross-Country Comparison - Estimated Weights in the Policy Objective (relative to inflation)

	Canada[1]	Australia[1]	New Zealand[1]	Brazil[2]	**Mexico**
μ_y	0.157	0.412	0.273	0.51	**0.468**
μ_r	0.855	0.611	0.850	0.63	**0.669**
μ_q	0.007	0.005	0.006	0.19	**0.004**

[1]Obtained from Kam, Lees, and Liu (2009).

[2]Obtained from Palma and Portugal (2014).

Figure 2: Posterior distributions