Central bank transparency under adaptive learning

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Abstract

The impact of central bank transparency on the evolution of agents' expectations for the Mexican case is evaluated in this paper via a New Keynesian model with adaptive learning and survey forecasts. Among multiple scenarios, the data prefer the observed transparency degree followed by the Mexican central bank, where the central bank not only credibly communicates the inflation target but also discloses relevant information about its policy rule. The results show that agents exhibit a faster learning speed than the U.S. and a declining perceived inflation persistence. Plus, the model-implied learning mechanism can match the empirical inflation expectations from the Survey on Expectations of Private Sector Specialists. Moreover, there is evidence suggesting that higher degrees of transparency increase the effectiveness of monetary policy in stabilizing the economy.

I. Introduction

"Clarity about the aims of future policy and about how the central bank likely would react under various economic circumstances reduces uncertainty and –by helping households and firms anticipate central bank actions –amplifies the effect of monetary policy."

Bernanke (2010)

Central bank transparency has been an important feature of monetary policy for the past decades. This is true for monetary policy authorities following an inflation targeting regime but also for those operating outside this framework. Institutional transparency promotes a greater openness which extends to publications of analysis and forecasts of the economic

environment, the central bank's policy agenda, minutes from the Board meetings, and, in some cases, explicit communication of the objective for inflation.

All these actions decrease the information gap between the monetary policymakers and the public. This allegedly helps the public to better understand the policy rule and leads to better anchor inflation expectations, and consequently, has a stabilizing effect on macroeconomic activity.

However, can these effects of central bank transparency be seen on agents' expectations formation and evolution? In order to answer this question, I will follow an adaptive learning approach that accommodates the two key assumptions. First, it allows for not perfectly anchored expectations. Plus, it posits that agents lack knowledge of the true model of the economy and the monetary policy conducted by the central bank.

Some examples of literature linking central bank transparency and adaptive learning include Berardi and Duffy (2007), Eusepi (2005), Orphanides and Williams (2007), and Eusepi and Preston (2010). The first two papers examine the effects of central bank transparency on the performance of optimal inflation targeting rules. Berardi and Duffy (2007) construct a model where central bank transparency allows the private agents to correctly specify their Perceived Law of Motion for inflation and output gap; thus, they can converge to the rational expectations equilibrium. The authors find that the policy loss from central bank transparency is lower than its alternative (i. e., intransparency). Eusepi (2005) posits transparency as the economic agents' knowledge of the monetary policy rule. Thus, the central bank transparency reduces agents' uncertainty, as the central bank communicates the policy rule. He finds that a transparent central bank plays an important role in stabilizing the public's learning process and expectations of the public.

While Orphanides and Williams (2007) model transparency by assuming that agents incorporate the information of the announcement of the inflation target into their learning algorithm. So, in this manner, they need to estimate a smaller number of parameters compared to the case where they did not receive this information. They point out that central bank transparency, including explicit communication of the inflation target, can influence inflation expectations by facilitating the learning of the central bank policy and, consequently, improving macroeconomic performance.

Finally, Eusepi and Preston (2010) explore the effects of different central bank communication strategies on expectations stabilization and the learning mechanism of the agents. That is to say; they evaluate the value of monetary policy information. Even when the paper uses different terminology, central bank communication can be closely related to the term

of *transparency*. They find that a more transparent monetary policy authority can prevent expectation-driven fluctuation as agents are capable of constructing more accurate forecasts.

Similar to all the previously mentioned work, this paper models central bank transparency as the available information about the monetary policy that economic agents have at their disposal. Nevertheless, it contrasts with them as it does not focus on the stability of the rational equilibrium but on the empirical role of central bank transparency on the learning process used by economic agents while they form expectations.

Along these lines, this paper aims to contribute to the literature by estimating, via Bayesian methods, a baseline New Keynesian model with adaptive learning to empirically study the effects of central bank transparency on the agents' learning process and expectations. I propose four scenarios that consider different degrees of transparency; within each case, the central bank releases various information related to the conduction of the monetary policy. Additionally, I incorporate time series information about expectations on inflation and nominal interest rate taken from the Survey on Expectations of Private Sector Specialists conducted by the Mexican central bank to identify the best-fitting evolution of agents' beliefs, as well as the learning speed.

The empirical analysis focuses on the Mexican experience as numerous measures of central bank transparency had been implemented during the last decades, in addition to the adoption of the inflation targeting framework in 2001. Plus, after experiencing chronic high inflation during the 70s and 80s and a disinflation process in the 90s, interrupted by the Tequila crisis, the central bank has successfully reduced and stabilized inflation and inflation expectations (Ramos-Francia and Torres (2005)). In the past two decades, the economy has shown a period of moderate but persistent inflation. Table 1 summarizes the communication strategy of the Mexican central bank.

Moreover, previous literature on the Mexican case has not explored the adaptive learning approach yet to analyze the effect of central bank transparency on the learning process of agents and their expectations.[1]

The results show that the partially transparent regime best fits the data among all four specifications. Other findings indicate that private agents exhibit a fast learning speed; they react strongly to forecast errors. Also, results indicate that agents' perception of inflation persistence has decreased over time.

[1]There are some recent papers, Ramos-Francia et al. (2018) and López-Martín et al. (2018), that consider the assumption that agents updated their beliefs using a constant-gain algorithm (as in Sargent et al. (2009)) to study, in contrast, the interaction between inflation, inflation expectations, and fiscal deficits in Mexico.

Implementation date	Transparency measures description
2000	Release of a Quarterly Report on Inflation.
2001	Inflation targeting framework adoption.
2003	Announcement of a band for the inflation target (3% $\pm$ 1%)
	Press releases on the Meeting of Banco de México's Governing Board regarding monetary policy decisions, plus disclosure of the dates of the meeting in advance.
2010	Release of a Quarterly Report on Inflation in English.
	Fan charts are incorporated into the Quarterly Report on Inflation.
2011	Publication of minutes on the Meeting of Banco de México's Governing Board.
2012	Online broadcasting of the Quarterly Report.
2017	Disclosure of the (anonymous) votes of Banco de México's Governing Board on monetary policy decisions.
2018	Disclosure of the voter identities of Banco de México's Governing Board on monetary policy decisions.
	Release of the transcript from the Meeting of Banco de México's Governing Board regarding monetary policy decisions, after 3 years of the reunion.
	Publication of Governing Board's speeches and presentations, after 2 days of their exposition.
2019	Figures on the Quarterly Report are accompanied with a link to the source of the data used on them.

Table 1: *Banco de México transparency timeline.*

Accordingly to the estimation, central bank transparency has a relatively small impact on inflation and output gap responses to structural shocks. Nonetheless, the results suggest that higher degrees of transparency increase the effectiveness of the monetary policy in stabilizing the economy and monetary policy expectations of the public.

Finally, the model-implied one-period-ahead inflation expectations are able to closely match the empirical expectations from the surveys of professional forecasters. Then this gives some evidence that the learning process estimated by the model resembles the one followed by the agents in the Mexican economy.

Monetary policy implications for this paper come from two routes. First, expectations are the channel through which monetary policy impacts the economy. Second, as Bernanke (2007) points out, *"a fuller understanding of the public's learning rules would improve the central bank's capacity to assess its own credibility, to evaluate the implications of its policy decisions and communication strategy, and perhaps to forecast inflation"*. Also, he emphasizes that inflation

expectations can heavily influence actual inflation thus, their understanding is crucial for policymakers.

The paper is organized as follows. Section II describes the model and how expectations are formed. Later, estimation and the results are discussed in Sections II and IV, respectively. Finally, the paper is concluded in Section V.

II. The Model

A basic New Keynesian model,[2] as presented in Woodford (2003), is followed to describe the economy dynamics.[3,4]

$$\pi_t = \hat{E}_{t-1}(\kappa x_t + \beta \pi_{t+1} + u_t) \tag{1}$$

$$x_t = \hat{E}_{t-1}(x_{t+1} - \sigma(i_t - \pi_{t+1} - r_t^n)) \tag{2}$$

$$i_t = \rho i_{t-1} + (1-\rho)(\chi_\pi \pi_{t-1} + \chi_x x_{t-1}) + \varepsilon_t^{mp} \tag{3}$$

where π_t, x_t and i_t are inflation, output gap and interest rate, respectively.

The New Keynesian Phillips Curve is described by Equation (1). It is derived from the firm's problem solution under a competitive monopoly and Calvo price setting environment. It shows the inflation dynamics given the expected path for output gap in $t+1$, the future inflation, and the cost-push shock, u_t. κ is a decreasing function of the degree of price stickiness, and β is the discount factor.[5]

Next, Equation (2) represents the Euler equation that arises from the households' optimal choice of consumption. In this equation can be seen that the output gap depends on its future expected levels and deviations of the real interest rate from the natural rate of interest, r_t^n. But most importantly, the output gap depends on expectations about the nominal interest rate. Now, aggregate demand is affected by the expectations of the central bank decisions. As

[2]As a closed-economy model, it does not consider the foreign sector and the exchange rate which are relevant characteristics for an economy as the Mexican. In spite of this limitations, I selected this model for simplicity, and since the main objective study the role of central bank transparency on the formation of expectations; and not the analysis of the external sector.

[3]All variables are expressed as log-deviations from their steady-state values.

[4]This model does not explicitly consider an inflation target, then, it is assumed that the target pursued by the central bank corresponds to the steady-state value of inflation.

[5]The discount factor is calibrated to 0.9946, which is the value consistent with the average of the real interest observed during the sample period.

previously mentioned, this will allow to identify the role of central bank transparency in the economy.

A Taylor-type interest rate rule is presented in Equation (3). It describes how the central bank conducts the monetary policy. That is to say, how the nominal interest rate evolves over time in reaction to changes in the levels of output gap and inflation. Responses of the monetary authority are captured by χ_π and χ_x, while ρ reflects any history dependence in the monetary policy.

Finally, the structural shocks of the system are denoted as ε_t^{mp}, u_t, and r_t^n:

$$\varepsilon_t^{mp} \overset{iid}{\sim} N(0, \sigma_{mp}^2) \tag{4}$$

$$u_t = \rho_u u_{t-1} + \varepsilon_t^u \tag{5}$$

$$r_t^n = \rho_r r_{t-1}^n + \varepsilon_t^r \tag{6}$$

where the cost-push shock and the natural rate of interest follow an AR(1) process. Meanwhile, the monetary policy shock, ε_t^{mp}, is assumed to be independently and identically distributed with homoskedastic variance. The same assumptions hold for $\varepsilon_t^u \overset{iid}{\sim} N(0, \sigma_u^2)$ and $\varepsilon_t^r \overset{iid}{\sim} N(0, \sigma_r^2)$.

So far, the model follows the benchmark New Keynesian model. However, it deviates from the rational expectations assumption. Following the literature on adaptive learning, I assume that economic agents behave as econometricians and forecast their expectations using an economic model and past data. Let $\hat{E}_t(.)$ denotes subjective expectations.

Additionally, I suppose that agents dispose of information up to period $t-1$,[6] thus, prices and consumption decisions are predetermined. This assumption allows me to introduce two elements to the analysis: i) the role of central bank transparency via expectations about nominal interest rate, and ii) survey data on expectations which are usually estimated one period in advance.

i. Central bank transparency and expectation formation

Moreover, I assume that the central bank transparency degree impacts the model used by agents to compute their expectations on future conditions of the economy and the monetary

[6]This is referred to as the “standard timing" assumption in Evans and Honkapohja (2001). It has the advantage of avoiding simultaneity issues between regressors and parameters in the model used by the agents to form their expectations.

Central banks communicates:	**Full transparency**	**Partial transparency**	**Only target known**	**Opacity**
Monetary policy coefficients	✓	-	-	-
Relevant variables for monetary policy	✓	✓	-	-
Inflation target	✓	✓	✓	-

Table 2: *Central bank transparency regimes.*

policy. I posit four scenarios assuming different degrees of central bank transparency. Table 2 summarizes the assumptions of the different degrees of transparency proposed.

Assuming that agents observe the structural shocks and use all available information communicated by the central bank, they compute the following model:

$$Z_t = a_t + b_t Z_{t-1} + c_t u_{t-1} + d_t r^n_{t-1} + e_t \tag{7}$$

where $Z_t = \{\pi_t, x_t, i_t\}'$ is a vector containing the endogenous variables of the model; a_t, b_t, c_t and d_t are a matrix and vectors of appropriate dimensions containing the beliefs.

Equation (7) is known as the Perceived Law of Motion (PLM), and it describes the model used by the agents to form their expectations about relevant variables. Note that agents are allowed to learn about the economy (π_t and x_t) and the monetary policy rule (i_t). The model for the nominal interest rate will assess the public's perception of the monetary policy under each of the four specifications proposed considering different degrees of central bank transparency.

It is important to remark that central bank releases will impact the PLM of monetary policy of the agents, since they will be exposed to different sets of information. For example, under *fully transparency* and *partial transparency*, the central bank credible communicates the target for inflation and the relevant variables for monetary policy. Thus, agents will not include an intercept in their PLM nor will consider the past information of the structural shocks for their model to forecast the nominal interest rate. See more details in Appendix A.

In this sense, central bank transparency facilitates the learning process because it reduces the number of parameters to be estimated by the agents in order to form their expectations. In contrast, in the *opaque* regime, agents do not receive any information from the central bank regarding its objectives nor the data it takes into account while making monetary policy decisions. So, the agents' PLM for nominal interest rate will consider an intercept and the lagged information about the structural shocks.

Agents update their estimates of the PLM coefficients each time new information is

available using a Constant-Gain learning algorithm:

$$\Phi_t = \Phi_{t-1} + gR_t^{-1}X_t(Z_t - X_{t-1}'\Phi_{t-1}) \tag{8}$$

$$R_t = R_{t-1} + g(X_tX_t' - R_{t-1}) \tag{9}$$

where g is the constant gain parameter, X_t is the set of regressors used in the PLM, and $\Phi_t = (vec(a_t', b_t)')'$. Recall that the model used by agents for the nominal interest rate will differ as a result of central bank transparency degree. Then, X_t, R_t and Φ_t will be adjusted to the assumed information set available to the public.

Equations (8) and (9) give the updating rules for the beliefs, Φ_t, and the matrix of second moments of the regressors employed in the PLM, R_t.

Therefore, agents form their expectations for t and $t+1$ using the PLM, the most recent coefficient estimates, and all available information regarding monetary policy published by the central bank:[7]

$$\hat{E}_{t-1}\begin{pmatrix}\pi_t\\ x_t\\ i_t\end{pmatrix} = \begin{pmatrix}a_{1,t}\\ a_{2,t}\\ a_{3,t}\end{pmatrix} + \begin{pmatrix}b_{11,t} & b_{12,t} & b_{13,t}\\ b_{21,t} & b_{22,t} & b_{23,t}\\ b_{31,t} & b_{32,t} & b_{33,t}\end{pmatrix}\begin{pmatrix}\pi_{t-1}\\ x_{t-1}\\ i_{t-1}\end{pmatrix} + \begin{pmatrix}c_{1,t}\\ c_{2,t}\\ c_{3,t}\end{pmatrix}u_{t-1} + \begin{pmatrix}d_{1,t}\\ d_{2,t}\\ d_{3,t}\end{pmatrix}r_{t-1}^n + \begin{pmatrix}0\\ 0\\ e_{t-1}^i\end{pmatrix} \tag{10}$$

$$\hat{E}_{t-1}\begin{pmatrix}\pi_{t+1}\\ x_{t+1}\\ i_{t+1}\end{pmatrix} = \begin{pmatrix}a_{1,t}\\ a_{2,t}\\ a_{3,t}\end{pmatrix} + \begin{pmatrix}b_{11,t} & b_{12,t} & b_{13,t}\\ b_{21,t} & b_{22,t} & b_{23,t}\\ b_{31,t} & b_{32,t} & b_{33,t}\end{pmatrix}\hat{E}_{t-1}\begin{pmatrix}\pi_t\\ x_t\\ i_t\end{pmatrix} + x\begin{pmatrix}c_{1,t}\\ c_{2,t}\\ c_{3,t}\end{pmatrix}E_{t-1}u_t + \begin{pmatrix}d_{1,t}\\ d_{2,t}\\ d_{3,t}\end{pmatrix}E_{t-1}r_t^n + \begin{pmatrix}e_{t-1}^\pi\\ 0\\ 0\end{pmatrix} \tag{11}$$

where e_t^π and e_t^i are expectation shocks related to inflation and the nominal interest rate, as in Milani (2011). They are assumed to be independent and follow an AR(1) process:

$$e_t^\pi = \rho_{e^\pi}e_{t-1}^\pi + \varepsilon_t^{e^\pi} \tag{12}$$

$$e_t^i = \rho_{e^i}e_{t-1}^i + \varepsilon_t^{e^i} \tag{13}$$

where $\varepsilon_t^{e^j} \overset{iid}{\sim} N(0, \sigma_{e^j}^2)$ for $j = \{\pi, i\}$. Recall that vectors a_t, c_t and d_t and matrix b_t change accordingly to the degree of central bank transparency.

These expectation shocks reflect exogenous variations on expectations unrelated to fundamentals. So, they can capture sentiments or psychological factors that affect expectations formation.[8] In order to extract a better signal of these expectation shocks and the learning process, I will be using data on expectations during the estimation of the model.

[7]While forming expectations about the structural shocks, agents are assumed to know their autocorrelation coefficients, but they do compute expectations about these shocks.

[8]In this case, I did not consider expectation shocks for output gap expectations as this paper focuses mainly in inflation and monetary policy.

Therefore, the model can be summarized by the economy dynamics, described in Equations (1)-(6); the agents' PLM, captured by Equation (7); the updating rules, expressed in Equations (8) and (9); and the forecasting rule shown in Equations (10) and (11).

III. Bayesian Estimation

The structural parameters are estimated via Bayesian techniques, following Herbst and Schorfheide (2016). First, a prior distribution is assigned to the parameters: $p(\theta)$, based on past literature. Then, the likelihood is obtained using the Kalman filter: $L(Y_{t=1:T}|\theta)$. A random-walk Metropolis-Hastings algorithm is implemented to estimate the posterior distribution of the parameters. I run 500,000 iterations, discarding 25% of the draws as the burn-in period. The posterior means are used as estimates for the parameters of the model.

i. State-space form

The model with adaptive learning expressed by Equations (1)-(6) and with agents' expectations formed as in (10) and (11) can be expressed in state-space form:

$$S_t = F_t S_{t-1} + G\varepsilon_t + \tilde{C}_t \tag{14}$$

$$Y_t = BS_t + m_t \tag{15}$$

where ε_t=(ε_t^{mp},ε_t^u,ε_t^r) are the structural disturbances; S_t is a state vector which includes endogenous variables, $S_t = (\pi_t, x_t, i_t, u_t, r_t^n, E_{t-1}\pi_{t+1}, E_{t-1}x_{t+1}, E_{t-1}i_{t+1}, E_{t-1}u_{t+1}, E_{t-1}r_{t+1}^n, E_{t-1}\pi_t, ...$ $E_{t-1}x_t, E_{t-1}i_t, E_{t-1}u_t, E_{t-1}r_t^n, e_t^\pi, e_t^i)$; Y_t is the vector of observable variables, Y_t=(π_t,x_t,i_t,$E_{t-1}\pi_{t+1}$, $E_{t-1}i_t$); B is a matrix compose of zeros and ones whence the variable is observable; m_t are the measurement errors;[9] and F_t, G and $\tilde{C}_t$ are matrices composed by the structural parameters, θ:

$$\theta = (\sigma, \kappa, \rho, \chi_\pi, \chi_x, \rho_u, \rho_r, \sigma_{mp}, \sigma_u, \sigma_r, g, \rho_{e^\pi}, \rho_{e^i}, \sigma_{e^\pi}, \sigma_{e^i}) \tag{16}$$

While F_t and $\tilde{C}_t$ also depend on the PLM reduced-form parameters, Φ_t.[10]

Equations (14) and (15) are the state-transition and measurement equations, respectively.

[9]Measurement errors are only assumed for the time-series for $E_{t-1}\pi_{t+1}$ and $E_{t-1}i_t$ since the first one is taken from a survey and the latter is computed. They are assumed to be 30% of the variance of the observable series.

[10]The initial values for agent beliefs are set as 0.7 for the persistence for all variables, while the perceived reaction coefficients of the monetary policy to inflation and output gap are chosen close to the Taylor (1993) values, 1 and 0.5, respectively.

ii. Data

The data used for the estimation has a quarterly frequency, and it comprises the period between 2001-I and 2018-IV. This choice relies on information availability and the paper's objective; to study the evolution of expectations during a period when the Banco de México followed transparency measures.

Inflation was constructed using the Mexican CPI (in Spanish Índice Nacional de Precios al Consumidor, INPC).[11] Output gap is estimated as the log difference of the detrended and seasonally adjusted Mexican GDP (in Spanish Producto Interno Bruto, PIB). Finally, the interest rate measure is taken from the 91 days yield Certificates of the Treasury of the Federation rate (in Spanish Certificados de la Tesoreria de la Federación, CETES), which are government securities equivalent to the 3-month T-bill.

Additionally, I incorporate time series information about inflation and nominal interest rate expectations. The one-period-ahead inflation expectations are taken from the Survey on Expectations of Private Sector Specialists conducted by the Mexican central bank. I use the mean across all available answers. Meanwhile, the expected nominal interest rate is computed using the expectation theory of the term structure, as information is not available. For this estimation, data on 91 and 182 days yield Certificates of the Treasury of the Federation rate is used.

All variables are expressed as deviations from the sample averages and expressed as quarterly rates.

The series for INPC and PIB were obtained from INEGI (Instituto Nacional de Estadística y Geográfica) and CETES information was acquired from Banco de México.

iii. Priors

The prior distributions used in the Bayesian estimation of the baseline New Keynesian model with adaptive learning for the Mexican case can be seen in Table 3.

The choice of the priors is based on previous literature related to New Keynesian model estimation, learning, and the Mexican case. Following Milani (2011), a gamma prior was assigned to the inter-temporal elasticity of substitution, σ, with mean of 1 and a sizable standard deviation, as there is a large uncertainty on its value in the literature. For the

[11] As the Mexican central bank does not react to the GDP deflator in practice, CPI is considered as the measure of inflation despite the model being a closed-economy one.

Parameter	Description	Distribution	Mean	SDs
σ	IES	Gamma	1	0.75
κ	Slope of PC	Gamma	0.5	0.2
ρ	Interest rate smoothing	Beta	0.8	0.1
χ_π	Inflation response coefficient	Gamma	1.5	0.25
χ_x	Output gap response coefficient	Gamma	0.5	0.25
ρ_u	AR coefficient - Cost-push shock	Beta	0.8	0.1
ρ_r	AR coefficient - Demand shock	Beta	0.8	0.1
σ_{mp}	SD - MP shock	Inverse Gamma	1	0.5
σ_u	SD - Cost-push shock	Inverse Gamma	1	0.5
σ_r	SD - Demand shock	Inverse Gamma	1	0.5
g	Constant gain	Uniform	0.5	$\sqrt{\frac{1}{12}}$
ρ_{e^π}	AR coefficient - Expectational shock for π	Beta	0.8	0.1
ρ_{e^i}	AR coefficient - Expectational shock for i	Beta	0.8	0.1
σ_{e^π}	SD - Expectational shock for π	Inverse Gamma	1	0.5
σ_{e^i}	SD - Expectational shock for i	Inverse Gamma	1	0.5

Table 3: *Prior distributions.*

autoregressive coefficients of the structural and expectational shocks, and the interest rate smoothing a Beta distribution center at 0.8 was used, as in Best (2013). The same paper was followed to choose the prior for the slope of the Phillips curve, κ. As most of the literature, the priors for the feedback of inflation and output gap in the Taylor-type rule were centered on the values estimated by Taylor (1993). At the same time, inverse gamma priors are chosen for the standard deviations of the structural and expectational disturbances. Lastly, a uniform distribution bounded in the $[0, 1]$ interval is assigned as a prior for the constant-gain parameter, g. In this manner, there are no pre-judgments attached to the learning process.

IV. Results

In this section, I present the estimation results. Firstly, I estimate the model under the four scenarios considering contrasting degrees of central bank transparency to asses which is able to better explain the data for the Mexican case. Arguably the *partially transparent* regime is

the most realistic case for the modern Mexican experience. However, I let the data speak and estimate all scenarios.

Next, I present the results for the scenario with the best performance: partial transparency.

i. Transparency degrees: an empirical comparison

First, I compare the marginal likelihoods and posterior odds for the specifications under different degrees of transparency. Table 4 shows the results. It can be seen that the model under a partially transparent regime fits the data better than all other regimes. In particular, the difference is significant when contrasting it versus the opaque scenario (posterior odds 8 x 10^4). These results may suggest that the empirical evidence supports the existence of a high degree of transparency in Mexico, where the central bank not only credibly communicates the inflation target but also discloses the relevant information so the public can better understand how the monetary policy is conducted.

	Full transparency	**Partial transparency**	**Only target known**	**Opacity**
Log marginal likelihood	-274.47	-272.00	-275.80	-283.29
Posterior odds	12	1	45	8 x 10^4

Table 4: *Model comparison under different degrees of central bank transparency.*

Additionally, I would like to investigate further the impact of central bank transparency on inflation, output, and expectations. In order to do so, I compute impulse response functions of these variables to various shocks under the different degrees of central bank transparency, see Figure 1 and 2.

Let us recall that inflation and output gap indirectly depend on how agents are forming their expectations on monetary policy via the aggregate demand channel, consequently on central bank transparency. In these lines, I examine the response of output and inflation to the structural shocks. For the cases of the cost-push and demand shocks, their magnitude within different degrees of transparency is quite similar. In contrast, the impact of the monetary policy shock show is increasing with the degree of transparency. Thus, the effectiveness of monetary policy is closely related to central bank transparency.

On the other hand, inflation expectations seem to be slightly more reactive, or less anchored in Bernanke's terms, when the central bank decides not to disclose relevant information about monetary policy conduction, such as the inflation target and the variables

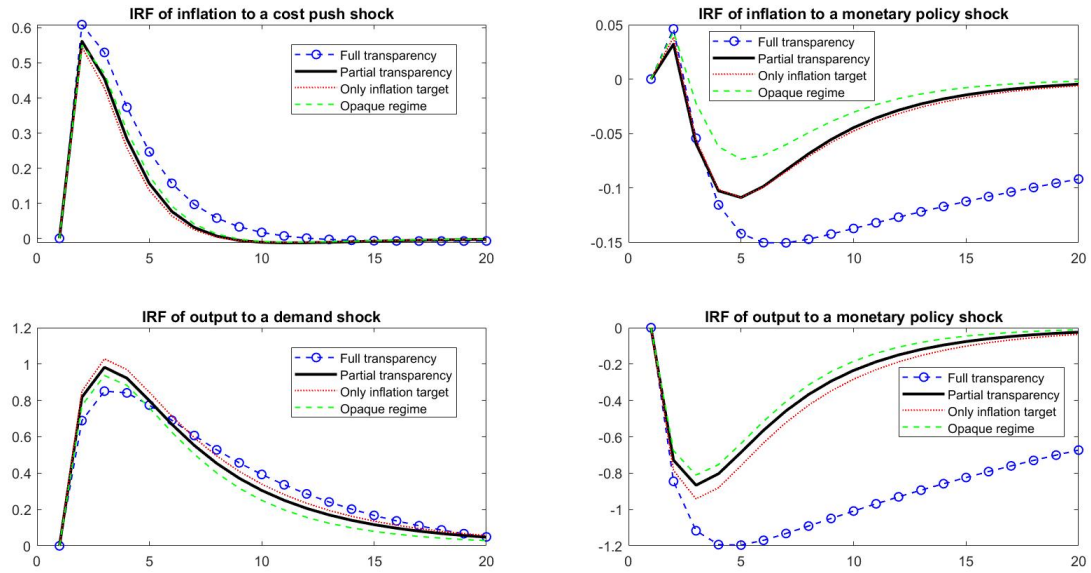


Figure 1: *Impulse response function of inflation and output gap under different degrees of central bank transparency.*

included in the rule used by the monetary authority. Whereas monetary policy expectations react highly when the public is exposed to the highest degree of transparency, especially to monetary policy shocks. Overall, higher degrees of transparency seems to deliver a better management of the public's inflation expectations.

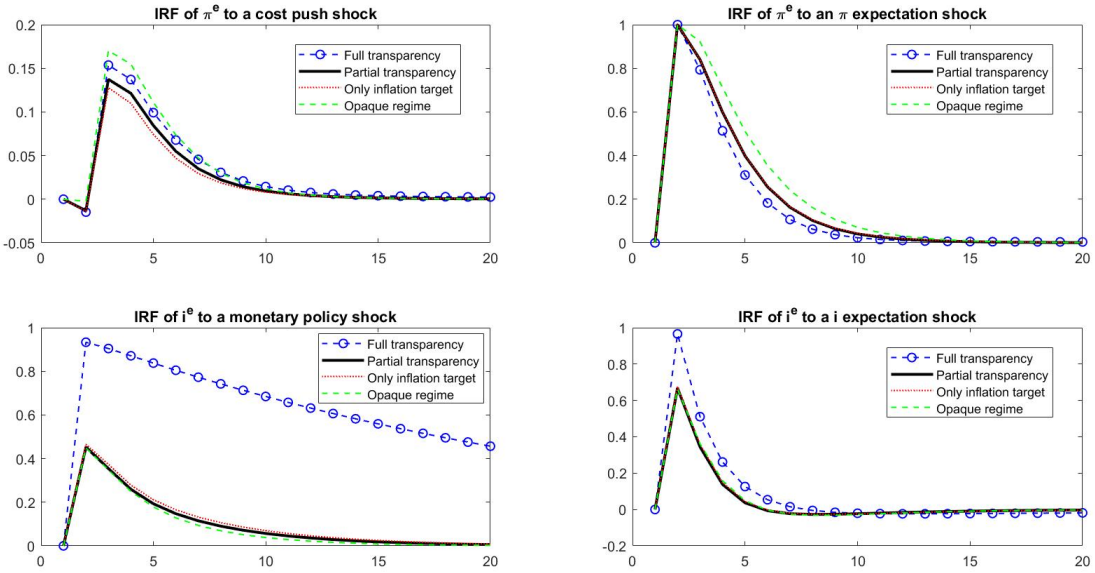


Figure 2: *Impulse response function of expectations under different degrees of central bank transparency.*

In contrast, interest rate expectations are formed similarly under most scenarios except for

full transparency, where agents heavily adjust their expectations about the future of monetary policy. In this case, the publication of all monetary policy information (i.e., the monetary policy rule coefficients) seems to increase the reaction of the public's interest rate expectations.

ii. The partially transparent regime: empirical findings

In this subsection, I present the estimation results for the scenario that better fitted the data: partial transparency. That is to say, when the target for inflation and the relevant variables for monetary policy decisions are credibly and clearly communicated by the central bank, but agents still have to estimate beliefs about the monetary policy rule coefficients. First, I discuss the estimates of the structural parameters. Next, the evolution of the agent's beliefs is described. Later on, the inflation expectations implied by the model are compared to the actual inflation dynamics and the expectations from the Survey on Expectations of Private Sector Specialists.

ii.1 Structural parameters

Table 5 shows the parameter estimates under the partially transparent regime for the Mexican case. According to the results, the monetary policy rule presents a feedback coefficient to inflation and output gap equal to 1.42 and 0.26, respectively, and a sizable history dependence. This suggests that the Mexican monetary policy rule exhibits a strong reaction to inflation and complies with the Taylor Principle. Also, Eusepi (2005) suggests that nominal interest smoothing makes the monetary policy more predictable, which can help the learning process of the economic agents. The posterior mean for the New Keynesian Phillips Curve slope is 0.23, which is lower than the one estimated by Best (2013) for the period 1995-2005, 0.44. This may be evidence supporting a smaller reaction of inflation to movements in the output gap in the past decade; namely, the economy is presenting a higher degree of price stickiness. Meanwhile, the intertemporal elasticity of substitution estimate is 0.8, similar to previous findings in the literature. Recall that σ will capture the demand channel of the monetary policy. Then, in this case, the effect of expected monetary policy decisions seems to have a near one-to-one impact on the aggregate demand.

As the focus of this paper is the learning process, a key parameter is the constant-gain coefficient, as it reflects the learning speed; higher values of g would imply faster learning. The posterior estimates suggest a relatively high learning speed but still within the range proposed by Orphanides and Williams (2005). A constant-gain of 0.035 is equivalent to saying

Parameter	Posterior mean	5% percentile	95% percentile
σ	0.803	0.596	1.095
κ	0.233	0.120	0.364
ρ	0.883	0.774	0.953
χ_π	1.420	1.065	1.822
χ_x	0.259	0.102	0.514
ρ_u	0.580	0.434	0.727
ρ_{r^n}	0.892	0.811	0.949
σ_{mp}	0.345	0.297	0.400
σ_u	0.963	0.754	1.231
σ_{r^n}	1.114	0.813	1.510
g	0.035	0.025	0.047
$\rho_{e_p i}$	0.592	0.438	0.739
ρ_{e_i}	0.854	0.668	0.954
$\sigma_{e^{pi}}$	0.351	0.297	0.412
σ_{e^i}	0.362	0.298	0.434

Table 5: *Posterior estimates.*

that agents use 28.6 quarters of past information to compute their expectations, reflecting efficiency in how agents update the information used in their forecast. This result contrasts with the findings in the U.S. learning literature, implying that expectations for Mexican agents seem less sluggish.

ii.2 Beliefs evolution

In this subsection, I will address the evolution of agents' beliefs about inflation and monetary policy under the partially transparent regime. First, the evolution of agents' beliefs about inflation is reported in Figure 3. The solid line shows the evolution of the autoregressive coefficient of the inflation PLM, and it represents the perceived persistence of inflation. Agents' started the period with a high level of perceived persistence that decreased for most of the sample. A pronounced fall was observed in the first quarter of 2010. A transitory increment can explain this perceived drop in inflation caused by a spike in the prices of

certain vegetables due to adverse conditions of the weather.[12]

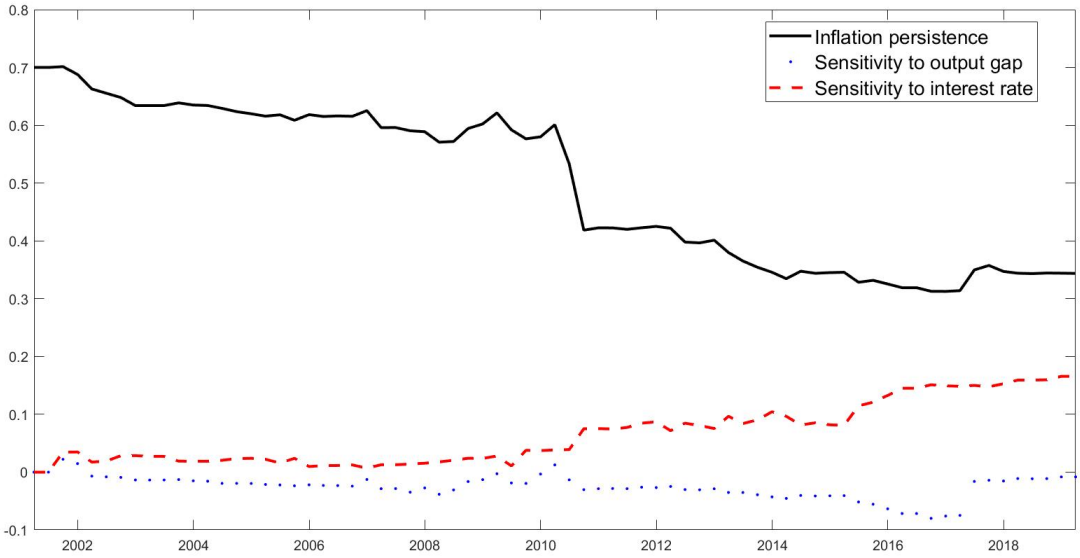


Figure 3: *Evolution of agents' beliefs about inflation.*

Additionally, Figure 3 shows the perceived sensibility of inflation to output gap and interest rate (dotted and dash lines, respectively). Beliefs show that inflation expectations are constructed under the belief that inflation is almost insensitive to changes in these variables, as the evolution of these coefficients remains close to zero. At the end of the sample, a slightly positive effect of the interest rate on inflation can be observed. Agents' learning seems to capture an episode of rising inflation, due to gasoline prices liberalization and external shocks as the uncertainty about U.S.-Mexico bilateral relationship associated to the new United States government, combined with a contractionary monetary policy that showed sluggish effects on inflation.

On the other hand, Figure 4 shows the evolution of agents' perceived coefficients of the monetary policy rule. The results suggest that despite the strong communication of the central bank, the public cannot learn the exact "structural" rule. Nonetheless, their perceptions of the monetary policy are close to the estimates, especially for the persistence. This result is particularly relevant as the central bank is implementing a strong interest rate smoothing. Moreover, at the end of the sample, agents wrongly believe that the feedback of output gap is higher than the one of inflation.

[12]Inflation Report, January-March 2010, Banco de México.

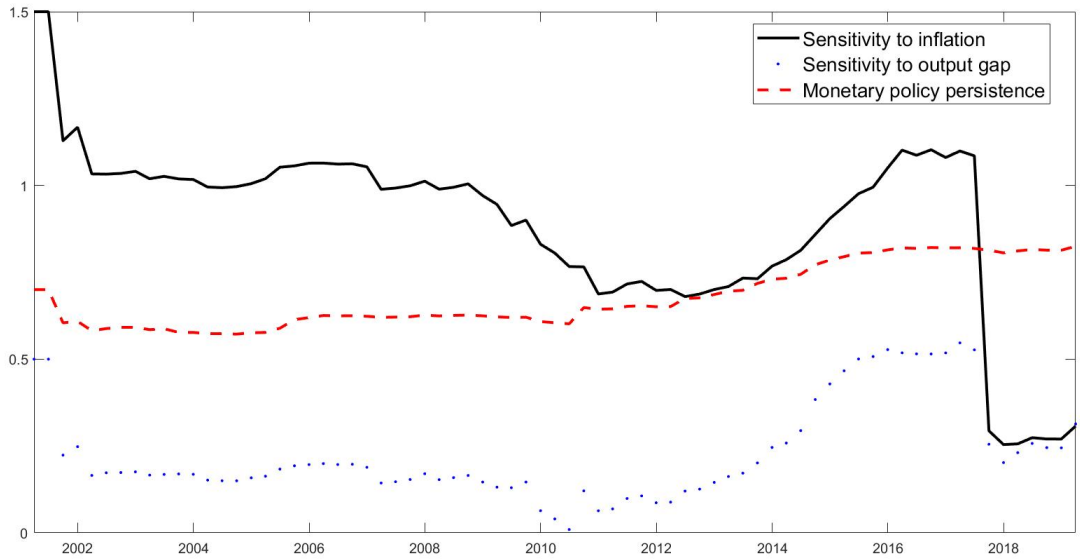


Figure 4: *Evolution of agents' beliefs about the monetary policy rule.*

ii.3 Inflation expectation: actual vs estimated

Next, I would like to analyze if the constant-gain learning algorithm generates plausible inflation expectations. In order to do this, I use inflation expectations data collected by the Mexican central bank.[13] Figure 5 contrasts the one-quarter ahead estimated expectations (dashed blue line) versus the inflation expected by professional forecasters (red line) from 2001 to 2018.[14] Overall, the results show that the match between model-implied and empirical inflation expectations is close. Particularly, the model captures the decline of expectations at the beginning of the sample and the continuous movement around a 4% mean. This coincidence between model forecasts and survey data gives some evidence that the learning process estimated for inflation resembles the one followed by the agents in the Mexican economy.

Nevertheless, the inflation expectations implied by the model are "flatter" than the observed inflation dynamics (black line), although both series move, more or less, across the same mean. The implications of the latter are twofold. First, the learning process fails to generate enough persistence, so the inflation expectations implied by the model resemble

[13]For reasons of comparability, the inflation expectations for the next quarter are taken from the survey. The professional forecasters formed their expectations in quarter t with information until quarter t-1. The mean across all the responses to the survey within each quarter is considered.

[14]The plot shows annualized rates.

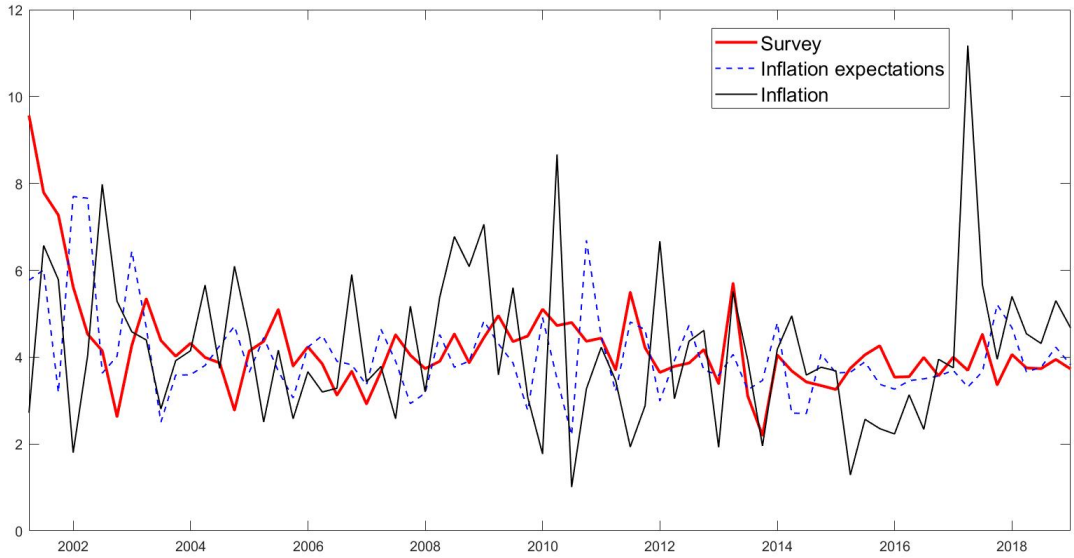


Figure 5: *Empirical and model implied inflation expectations: One-quarter ahead.*

the actual dynamics of inflation in the last two decades for the Mexican case. Second, the reduced perceived coefficients of inflation for persistence can suggest that the central bank has managed to well-anchored the agents' expectations, in the sense that they do not respond to movements in the actual inflation.

V. Conclusions and Future Research

This paper assesses the role of central bank transparency on the evolution of expectations and the economy for the Mexican case under an adaptive learning approach. The results show that the partially transparent regime, where the central bank communicates the inflation target and all relevant variables for the conduction of the monetary policy, exhibits the best fit to the data among all four specifications. This suggests that the Mexican central bank has been able to clearly and credibly communicate with the public, as economic agents consider all available information in the model used to form their expectations.

Other findings indicate there is evidence that private agents exhibit a fast learning speed, meaning that they react strongly to forecast errors. In contrast to the U.S. experience, Mexican agents seem to present a less sluggish process of forming their expectations.

Also, results indicate that agents' perception of inflation persistence has decreased over time, particularly since the 2010s. Plus, they formed their inflation forecasts under the belief

that this variable is almost unaffected by movements in the output gap. Together with the lower reaction of inflation expectations to structural and expectation shocks, in comparison to other central bank regimes, this may suggest that the partially transparent regime followed by the central bank has helped to better anchor inflation expectations. On the other hand, agents are not able to learn the “structural" monetary rule, with the exception being the perceived persistence of monetary policy, which is close to the estimate, despite the transparency measures of the central bank.

Accordingly to the estimation, central bank transparency has a relatively small impact on inflation and output gap responses to structural shocks. Nonetheless, the results suggest that higher degrees of transparency increase the effectiveness of the monetary policy in stabilizing the economy and monetary policy expectations of the public.

Additionally, the model-implied one-period-ahead inflation expectations is able to closely match the empirical expectations from the surveys of professional forecasters. Then, this gives some evidence that the learning process estimated by the model resembles the one followed by the agents in the Mexican economy.

In sum, the transparency adopted by the Mexican Central bank played a role in the evolution of agents' beliefs and expectations formation. As suggested by Orphanides and Williams (2007), it seems to promote a better guidance for the formation of inflation expectation since inflation responds less to shocks in contrast to the alternative central bank transparency scenarios. Nonetheless, it did not necessarily ease a perfect understanding of monetary policy.

Overall, this paper gets us closer to understanding how expectations are formed and how they are impacted by central bank transparency—both key issues for monetary policy.

In the future, additional elements could be incorporated into this paper to enrich the analysis. Some of these are discussed next.

Mexico as an small open economy. As mentioned at the beginning, the model does not consider two key elements that greatly impact the dynamics and expectations of inflation for the Mexican case: exchange rate and external sector. Considering an open economy model would allow to better explain both of these variables.

Inflation target: empirical vs observed. Currently, I am assuming that the target for inflation is equal to its steady-state value (or sample mean) for simplicity and because the sample mean is close to the upper band of the inflation target. Nevertheless, one issue I encountered during the estimation of the model was that the central bank's inflation target does not coincide with the sample mean for inflation. Therefore, some changes will be implemented to the model in

order to address this discrepancy.

Unique learning speed. Previous literature suggests the learning speed can differ across variables.[15] Then, allowing the constant-gain parameter for inflation, output gap, and nominal interest rate to be different from each other may lead to uncovering new lessons.

Supply channel for monetary policy. Finally, the model considered so far only exhibits a demand channel for monetary policy. Nevertheless, incorporating a supply channel would greatly enrich the analysis. Considering a model with a cost-channel of monetary policy, such as the one presented in Eusepi (2005), would make this possible.

[15] Branch and Evans (2006).

APPENDIX

A. Central bank transparency regimes

In this model agents are assumed to form expectation while learning about the economy and the monetary policy conducted by the central bank. In addition, and depending on the central bank transparency, the monetary policy authority communicates various information related to the policy conduction. This will impact the learning process of agents in this economy. In particular, the model for the nominal interest rate will adjust accordingly to the degree of level of transparency followed by the central bank.

The perceived models and the available information sets in each of the four proposed scenarios are explained below.

i. Opacity

CB communicates:	**MP rule coefficients**	**Inflation target**	**Variables in MP rule**
Opacity	-	-	-

Under an opaque regime, the PLM becomes:

$$Z_t = a_t + b_t Z_{t-1} + c_t u_{t-1} + d_t r^n_{t-1} + e_t$$

where:

$$a_t = \begin{pmatrix} a^\pi_t \\ a^x_t \\ a^i_t \end{pmatrix}; \quad c_t = \begin{pmatrix} c^\pi_t \\ c^x_t \\ c^i_t \end{pmatrix}; \quad d_t = \begin{pmatrix} d^\pi_t \\ d^x_t \\ d^i_t \end{pmatrix};$$

- $Z_t = \{\pi_t, x_t, i_t\}'$.
- a_t, b_t, c_t and d_t are estimated.

ii. Only target known

When only the inflation target is disclosed by the central bank, agents use the following model to form their expectations:

$$Z_t = b_t Z_{t-1} + c_t u_{t-1} + d_t r^n_{t-1} + e_t$$

CB communicates:	MP rule coefficients	Inflation target	Variables in MP rule
Only target	-	✓	-

where:

$$c_t = \begin{pmatrix} c_t^{\pi} \\ c_t^{x} \\ c_t^{i} \end{pmatrix}; \quad d_t = \begin{pmatrix} d_t^{\pi} \\ d_t^{x} \\ d_t^{i} \end{pmatrix};$$

- $Z_t = \{\pi_t, x_t, i_t\}'$.
- a_t is not estimated.

iii. Partial transparency

CB communicates:	MP rule coefficients	Inflation target	Variables in MP rule
Partial transparency	-	✓	✓

Under partial transparency, the model used by the agents to form their expectations is given by:

$$Z_t = b_t Z_{t-1} + c_t u_{t-1} + d_t r_{t-1}^n + e_t$$

where:

$$c_t = \begin{pmatrix} c_t^{\pi} \\ c_t^{x} \\ 0 \end{pmatrix}; \quad d_t = \begin{pmatrix} d_t^{i} \\ d_t^{x} \\ 0 \end{pmatrix}$$

- $Z_t = \{\pi_t, x_t, i_t\}'$.
- a_t, c_t^i, d_t^i are not estimated.
- b_t^i is estimated by agents.

iv. Full transparency

Under full and partial transparency, the PLM is given by:

$$Z_t = b_t Z_{t-1} + c_t u_{t-1} + d_t r_{t-1}^n + e_t$$

CB communicates:	MP rule coefficients	Inflation target	Variables in MP rule
Full transparency	✓	✓	✓

where:

$$c_t = \begin{pmatrix} c_t^{\pi} \\ c_t^{x} \\ 0 \end{pmatrix}; \quad d_t = \begin{pmatrix} d_t^{i} \\ d_t^{x} \\ 0 \end{pmatrix}$$

- $Z_t = \{\pi_t, x_t, i_t\}'$.
- a_t, b_t^i, c_t^i, c_t^i are not estimated.
- $\bar{b}^i$ is assumed to be equal to the coefficients estimated for the Taylor rule under rational expectations.

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