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Exchange Rate Pass-Through Conditional on Shocks and Monetary Policy Credibility: The Case of Uruguay☆

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Resumen

La estimación del traspaso del tipo de cambio (ERPT por sus siglas en inglés) es fundamental para comprender y proyectar la dinámica inflacionaria en economías abiertas. En este trabajo, estimamos un modelo Neokeynesiano de escala mediana para la economía uruguaya para analizar el ERPT. Calculamos el ERPT con un modelo estimado condicional en shocks externos específicos y en la credibilidad perfecta o imperfecta de la política monetaria. Los resultados muestran que el ajuste empírico es mejor al estimar el modelo con credibilidad imperfecta. El grado estimado de credibilidad imperfecta es significativo y muestra variaciones sustanciales entre distintos shocks y a lo largo de la muestra. Encontramos que el ERPT tiende a ser menor para shocks que tienen un mayor efecto compensador en la demanda agregada y cuando la política monetaria es más creíble en el mantenimiento de una meta de inflación constante. Finalmente, agregar la estabilización del tipo de cambio como determinante de la regla de política monetaria tiene, en el caso uruguayo, un papel empírico más fuerte cuando se contempla la posibilidad de credibilidad imperfecta.

JEL: E12, E58, F31, F41
Palabras clave: Traspaso de tipo de cambio a precios; Economía emergente; Credibilidad Imperfecta; Estimación Bayesiana

Abstract

The estimation of exchange rate pass-through (ERPT) is critical for understanding and forecasting the inflation dynamics in open economies. In this work, we estimate a medium scale New-Keynesian model for the Uruguayan economy to analyze the ERPT. We compute the ERPT with the estimated model conditional on specific external shocks and on whether the monetary policy has perfect or imperfect credibility. The results show that the empirical fit is better under imperfect credibility. The estimated degree of imperfect credibility is quite significant and it shows substantial variation across shocks and over time. We find that the ERPT tends to be lower for a shock that has a higher offsetting effect in aggregate demand and when monetary policy is more credible in keeping the inflation target constant. Finally, adding the exchange rate stabilization in the monetary policy rule in the case of Uruguay has a stronger empirical role once we allow for imperfect credibility.

Keywords: Exchange rate pass-through; Emerging economy; Imperfect credibility; Bayesian estimation.

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1 Introduction

The exchange rate is a relative price that determines the relative demand between domestic and foreign goods and the allocations of resources across relevant sectors (e.g. tradable vs non-tradable). At the same time, the dynamics of the exchange rate tend to affect the behavior of inflation. In the case of emerging economies with some degree of exchange rate flexibility, the control of inflation is usually affected by the exchange rate movement. This relationship is generally captured by the exchange rate pass-through (ERPT), which measures the size of the exchange rate variation that translates to domestic inflation. From a policy perspective, the degree of ERPT in a country affects the effectiveness of the exchange rate as a shock absorber to help to maintain the internal and external balance of an economy (see, e.g., Edwards (2006), Carrière-Swallow et al. (2016)). Also, the size of the ERPT limits the ability of the central bank to conduct a countercyclical monetary policy and control inflation (Vegh et al. (2017)).

This paper analyzes the factors that determine the ERPT by developing and estimating a New-Keynesian DSGE model to underscore the role of the type of shocks that hit the Uruguayan economy and the monetary policy credibility in shaping the ERPT. The model features nominal and real rigidities, but also an incomplete information mechanism to form inflation expectations that will depend on the degree of monetary policy credibility. The case of Uruguay is interesting not only because it has been influenced by significant external shocks like many other emerging economies but also because the exchange rate pass-through to prices is something that authorities are always monitoring. Moreover, in the sample considered (from 2005 to 2020) the Central Bank of Uruguay has undergone a transition to implement an inflation targeting regime, where anchoring inflation expectations depends critically on the degree of monetary policy credibility. Thus, important lessons to other emerging economies could be obtained from this case country estimation.

The bayesian estimation suggests the presence of imperfect credibility on the degree of anchoring of the inflation target perceived by the private sector. Moreover, we estimate a quite significant degree of imperfect credibility in the variation of the inflation target in response to shocks that affect the exchange rate. On average and in response to shocks, we estimate that around 60% of the times the economy is hit by shocks that affect the nominal exchange rate, the market perceives a change in the inflation target when we allow for imperfect credibility. Importantly, the bayesian model comparison stresses that the empirical fit of the model is about one thousand times better with imperfect credibility than with perfect credibility. We also infer substantial variation across shocks and over time of the importance of imperfect credibility in the period analyzed. Using the estimation of the model, we compute the ERPT as a function of the shock analyzed and of the monetary policy credibility. We find that the ERPT tends to be lower for a shock that has a higher offsetting effect in aggregate demand. We also estimate that the ERPT is lower when monetary policy is credible in keeping the inflation target constant.

A final result connects the exchange rate stabilization and the imperfect credibility. When the monetary policy is characterized with imperfect credibility in anchoring inflation expectations, we identify a much more intense stabilization of the exchange rate by setting the short-term interest rate. Also, when we restrict to a case with imperfect credibility, the empirical fit is better with the stabilization of the exchange rate in the monetary policy rule. However, if we assume that there is not a systematic exchange rate stabilization in the policy rule, then the model with perfect credibility is empirically superior to the model with imperfect credibility. This emphasizes that both ingredients, namely exchange rate stabilization and imperfect credibility, are jointly important to characterize the monetary policy in Uruguay. Each of these two ingredients in isolation is not enough to describe monetary policy in Uruguay.

The present study is related to a vast research about the ERPT for advanced and developing economies. One of the main conclusions of this literature is that product differentiation and invoicing currency of goods might explain the factors that condition the degree of ERPT (e.g. Campa and Goldberg (2005), Kamps (2006), Burstein and Gopinath (2014), Gopinath (2015)). Hence, higher compettition in the international market due to globalization will tend to reduce the observed ERPT, since firms have less degree of freedom to adjust prices.

Another conclusion of this empirical literature, stressed by Taylor (2000), is that lower and more stable inflation results in lower ERPT since this generates less persistent inflation and a less frequent need to change prices. The same logic has been used to explain why emerging economies have higher ERPT than advanced economies, since the former have lower credibility than the latter (Calvo and Reinhart (2002)). Reduction of the estimated ERPT after the adoption of an inflation targeting regime has reinforced this argument since this type of regime involves a stronger commitment to stabilize inflation as the primary goal of the central bank (see, for instance, Edwards (2006)). Carrière-Swallow et al. (2016) refine the analysis and use the degree of disagreement among professional forecasters of inflation as a measure of imperfect credibility of the monetary policy. They find that, for a given level and volatility of inflation, greater credibility of monetary policy acts to reduce the degree of ERPT.

However, most of these studies are based on reduced form estimations of the ERPT. The tapering announcements by the Fed in 2013, about the potential end to the quantitative easing policy, caused sharp depreciation of several currencies around the world and acceleration of inflation, raising the case that the observed reduction in the ERPT was over-estimated, especially in emerging economies. A natural question in this context is to analyze the role of the type of shocks affecting emerging economies in the observed reduction in the ERPT in recent decades. In other words, it is important to assess to what extent the observed reduction in the ERPT was due to the improvement in monetary policy in emerging economies and to the external conditions that affect them.

From a methodological point of view, most of the existing literature on the estimation of the ERPT has two caveats. First, there are endogeneity issues, since the nominal exchange rate and the prices in the economy are determined simultaneously and may be affected by the same shocks. This might lead to a bias in the estimated parameters and therefore incorrect inference about the degree of pass-through. Second, the ERPT is endogenous to monetary policy, which affects the coefficient estimates and should be taken into account; otherwise, it may lead to inaccurate policy decisions. We will address both of these shortcomings by estimating conditional measures of ERPT in a DSGE context. Our approach to obtain the ERPT through the estimation of a general equilibrium model that disentangles the shocks affecting the economy is related to Bouakez and Rebei (2008), García-Cicco and García-Schmidt (2020), and Palleja (2018).

These latter studies distinguish between conditional and unconditional measures of ERPT. The unconditional estimates are based on a single equation where inflation is regressed against the exchange rate depreciation and other controls. In contrast, the conditional ERPT aims to identify the underlying shocks affecting the exchange rate and inflation. In particular, using impulse response functions, the ERPT is measured as the ratio of the percentage change in a price index, relative to changes in the exchange rate when a specific shock hits the economy. Hence, movements in the exchange rate are conditional on a given shock, whereas the unconditional measure can be interpreted as an average across all shocks affecting the economy.

Although this paper shares a common methodology with these studies, we will incorporate the role of credibility in the monetary policy explicitly in the DSGE model. Therefore, our main contribution will be to analyze in the case of Uruguay how the conditional ERPT is affected by the type of shock hitting the economy and the degree of monetary policy credibility using the estimation of the DSGE model. Hence, we will complement the approach used by Edwards (2006), Borenszetin and Queijo (2016), Carrière-Swallow et al. (2016) to quantify the role of monetary policy credibility in affecting the ERPT.

Formally, we model imperfect credibility in monetary policy in a similar manner as Erceg and Levin (2003), where the degree of persistence of the deviations from the monetary policy rule is not fully observed by market participants. The credibility of monetary policy is related with the market perception of a more persistent deviation from the monetary policy rule in response to different shocks. This imperfect information regarding the duration of the monetary policy deviations from its systematic behavior generates a learning process by the market about the expected path for the monetary policy rule ahead. We introduce this learning process in a DSGE model for Uruguay and for each relevant shock that affects the exchange rate and inflation. Then, using a set of observable variables including private sector inflation expectations, we estimate the parameters of the model with Bayesian techniques. One important ingredient is the joint estimation of the coefficients associated to the imperfect credibility specification with the rest of the structural parameters.

For the base model, we develop a simplified version of Basal et al. (2016), who estimate a DSGE model for Uruguay that considers key aspects of this economy. In this model, the productive and price formation structure reflects the main analytical categories used in the short term analysis and monetary policy recommendations in the case of Uruguay. It includes nominal rigidities, trying to capture the transmission mechanisms and formation of domestic prices.

As a result of the estimation of the model under imperfect credibility, we are able to obtain the ERPT conditional on each shock. At the same time, we can determine the role of monetary policy credibility in affecting these conditional ERPT. Hence, our contribution will extend the structural analysis of the ERPT with a quantitative estimation of the role of monetary policy credibility in shaping the conditional ERPT.

The rest of the document is organized as follows. Section 2 lays out the small open economy model for the Uruguayan economy, which allows for the possibility of having imperfect credibility about monetary policy. Section 3 presents the model estimation for perfect and imperfect credibility. Section 4 discusses estimation applications regarding the quantitative role of imperfect credibility and how the ERPT depends on the shock hitting the economy and the degree of monetary policy credibility. Section 5 offers final remarks.

2 Model

In order to characterize the Uruguayan economy we develop a small open economy New Keynesian model. The model is based on Gali and Monacelli (2005), but it is extended in several aspects. As in Kam et al. (2009), it includes habits in consumption, indexation of prices to past inflation, and imperfect pass-through of the exchange rate to import prices in the local currency. In contrast to Kam et al. (2009), it considers imperfect financial integration, which is relevant in emerging economies, such as this Latin American country. The model is a medium size DSGE model since it is a simplified version of the model in Basal et al. (2016).

As in Basal et al. (2016), the model separates the commodities sector to capture the terms of trade shocks that significantly affect the Uruguayan exchange rate. For simplicity, the domestic commodity will be a stochastic endowment, fully exported and not consumed domestically.[1] The other sector (domestic goods) will produce using labor as input. Also, the model includes wage rigidities to better characterize the persistence in inflation through the inertia of wage inflation. Finally, we model the possibility of having imperfect credibility on monetary policy following Erceg and Levin (2003). We decompose the imported goods in two types. One type has an incomplete exchange rate pass-through in the short-run, while the other type has a full and fast exchange rate pass-through. This consideration reflects the observation that a significant fraction of foreign goods in Uruguay has short-run variation highly dependent of the exchange rate movement. This ingredient is included to have more discipline in the quantitative characterization of the ERPT in the case of Uruguay.

2.1 Households

The domestic economy is inhabited by a continuum of households indexed by $j \in [0, 1]$. The expected present value of the utility of household j is given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t \exp(\nu_t) \left[(C_t(j) - hC_{t-1})^{1-1/\sigma} - \frac{\kappa \exp(l_{s,t})}{1+\sigma_L} N_t(j)^{1+\sigma_L} \right], \qquad (1)$$

where $N_t(j)$ and $C_t(j)$ are labor effort and total consumption for household j, while C_t corresponds to the aggregate consumption. Parameter σ controls the curvature of preferences with respect to the argument $C_t(j) - hC_{t-1}$, this corresponds to intertemporal elasticity of substitution when $h = 0$. Parameter σ_L is the inverse elasticity of labor supply with respect to real wages and κ is a parameter that controls the labor disutility in the steady state. $\beta < 1$ is the subjective discount factor, ν_t is an intertemporal disturbance, and $l_{s,t}$ is a preference shock that shifts the labor supply. These last two exogenous variables follow independent autoregressive processes of order 1 (AR(1)). Preferences display habit formation in consumption, which is governed by parameter h and the aggregate consumption in the previous period, C_{t-1}.[2] The consumption bundle of household j will correspond to the *core* consumption, excluding perishable fruits and vegetables and regulated prices.[3] This *core* consumption is given by

$$C_t(j) = \left[\alpha_C^{\frac{1}{\eta_C}} \left(C_{F,t}(j)\right)^{\frac{\eta_C - 1}{\eta_C}} + (1-\alpha_C)^{\frac{1}{\eta_C}} \left(C_{H,t}(j)\right)^{\frac{\eta_C - 1}{\eta_C}} \right]^{\frac{\eta_C}{\eta_C - 1}}, \qquad (2)$$

[1] This is clearly the case for the cellulose and its related products, but for dairy products and meat a fraction is consumed internally.

[2] Note that the utility function is cashless given that the main monetary policy instrument is the short-term interest rate, but this representation is a simplification of having money holding as a separate argument in the utility function.

[3] Below we will explain how we add these excluded items in the total CPI basket.

where $C_{H,t}(j)$ represents a bundle of domestically produced goods (Home goods), and $C_{F,t}(j)$ corresponds to a bundle of imported goods (Foreign goods).

Parameter η_C is the elasticity of substitution between Home and Foreign goods, and α_C controls the weight of imported goods in this consumption basket. For any level of consumption, each household purchases a composite of Home and Foreign goods in order to minimize the total cost of its consumption basket. Hence, the demand functions for Home goods and Foreign goods are given by,

$$C_{H,t}(j) = (1-\alpha_C)\left(\frac{P_{H,t}}{P_{X,t}}\right)^{-\eta_C} C_t(j) \quad \text{and} \quad C_{F,t}(j) = \alpha_C \left(\frac{P_{F,t}}{P_{X,t}}\right)^{-\eta_C} C_t(j). \tag{3}$$

The price level of this consumption basket will be denoted by $P_{X,t}$ and is a core price index. Thus, the core price index is given by

$$P_{X,t} = \left[(1-\alpha_C)P_{H,t}^{1-\eta_C} + \alpha_C P_{F,t}^{1-\eta_C}\right]^{\frac{1}{1-\eta_C}}, \tag{4}$$

where $P_{H,t}$ and $P_{F,t}$ are the price of Home and Foreign goods, respectively.

Domestic households have access to four different types of assets: money $\mathcal{M}_t(j)$, one-period non-contingent domestic bonds $B_t(j)$, one-period non-contingent foreign bonds $B_t^*(j)$, and one-period domestic contingent bonds $D_{t+1}(j)$, which pay out one unit of domestic currency in a particular state. There are no adjustment costs in the portfolio composition. However, each time a domestic household borrows from abroad it must pay a premium over the international price of external bonds. This premium is introduced in the model to obtain well defined dynamics around the steady state of the economy.[4] Hence, the household budget constraint is:

$$E_t[\delta_{t,t+1}D_{t+1}(j)] + \frac{S_t B_t^*(j)}{R_t^*\Theta_t} + \frac{B_t(j)}{R_t} + \mathcal{M}_t(j) = \left[\begin{array}{l} D_t(j) + S_t B_{t-1}^*(j) + B_{t-1}(j) + \mathcal{M}_{t-1}(j) \\ +W_t(j)N_t(j) + \Omega_t(j) + T_t(j) - P_{X,t}C_t(j) \end{array}\right] \tag{5}$$

where R_t^* is the gross interest rate on the international bonds ($B_t^*(j)$), R_t is the gross interest rate in domestic bonds ($B_t(j)$), $\Omega_t(j)$ are profits received from domestic firms, S_t is the nominal exchange rate (units of domestic currency for one unit of foreign currency), $W_t(j)$ is the nominal wage set by household j, $T_t(j)$ are per capita lump sum net transfers from the government. The gross interest rate is a combination of three different factors:

$$R_t^* = R_t^{US}\xi_t\zeta_t$$

where R_t^{US} is the risk-free rate set by the Federal Reserve in US, ξ_t is the sovereign risk premium, and ζ_t is an exchange rate risk. Each of these three variables follow an AR(1)

[4]See Schmitt-Grohé and Uribe (2003) for different ways to get stationary dynamics for small open economy models.

process.

The term $\Theta_t = \Theta\left(B_t^*\right)$ corresponds to the premium domestic households have to pay each time they borrow from abroad, where $B_t^* = \int_0^1 B_t^*(j)dj$ is the aggregate net foreign asset position of the economy. Variable $\delta_{t,t+1}$ is the period t price of domestic contingent bonds normalized by the probability of occurrence of the specific state in $t+1$. For that reason, the expectation conditional in information at t, $E_t[\delta_{t,t+1}D_{t+1}(j)]$, is the portfolio of these contingents bonds. Assuming the existence of a full set of these contingent bonds ensures that consumption of all households is the same, independently of the labor income they receive each period given the wage rigidities they face.

Since the premium depends on the aggregate net foreign asset position of the economy, households take Θ_t as given when deciding their optimal portfolios. In other words, households do not internalize the effect on the premium of changes in their own foreign asset position. In steady state $\Theta\left(.\right)$ is parameterized so that:

$$\Theta\left(B^*\right) = \overline{\Theta}, \qquad \text{and} \qquad \frac{\Theta'\left(B^*\right)}{\Theta\left(B^*\right)}B^* = \varrho.$$

Here B^* corresponds to the steady state net foreign asset position. When the country as a whole is a net debtor, ϱ corresponds to the elasticity of the upward sloping supply of international funds.

Consumption and saving decisions. Households choose consumption and the composition of their portfolios by maximizing (1) subject to (5). Since we are assuming the existence of a complete set of contingent claims, consumption is equalized across households. Therefore, in what follows we can omit index j from consumption.

Labor supply decisions and wage setting. Each household j is a monopolistic supplier of a differentiated labor service. There is a set of perfectly competitive labor service assemblers that hire labor from each household and combine it into an aggregate labor service unit, N_t, that is then used by the intermediate goods producer. The labor service unit is defined as:

$$N_t = \left(\int_0^1 N_t(j)^{\frac{\epsilon_L - 1}{\epsilon_L}} dj\right)^{\frac{\epsilon_L}{\epsilon_L - 1}}, \tag{6}$$

where $N_t(j)$ is the labor supply of household j and ϵ_L is the elasticity of substitution between the labor supply across households. The optimal composition of this labor service unit is obtained by minimizing its cost, given the wages set by different households. In particular, the demand for the labor service provided by household j is:

$$N_t(j) = \left(\frac{W_t\left(j\right)}{W_t}\right)^{-\epsilon_L} N_t, \tag{7}$$

where $W_t\,(j)$ is the wage rate set by household j and W_t is an aggregate wage index defined as

$$W_t = \left(\int_0^1 W_t(j)^{1-\epsilon_L} dj \right)^{\frac{1}{1-\epsilon_L}}. \tag{8}$$

Following Erceg et al. (2000), we assume that wage setting is subject to a nominal rigidity à la Calvo (1983). In each period, each type of household faces a constant probability $(1-\theta_w)$ of being able to re-optimize its nominal wage. We assume there is an updating rule for all those households that cannot re-optimize their wages. In particular, if a household cannot re-optimize during i periods between t and $t+i$, then its wage at time $t+i$ is given by

$$W_{t+i}(j) = \Gamma_{W,t}^i W_t(j), \tag{9}$$

where $\Gamma_{W,t}^i$ describes an adjustment rule for wages, that is defined as:

$$\Gamma_{W,t}^i = \prod_{j=1}^{i} (1+\pi_{t+j-1})^{\chi_w} (1+\bar{\pi})^{1-\chi_w}.$$

This "passive" adjustment rule implies that workers who do not optimally reset their wages update them by considering a geometric average of past headline inflation (with weight χ_w), defined as $\pi_t = CPI_t/CPI_{t-1} - 1$ and inflation target (with weight $1-\chi_w$), $\bar{\pi}$.[5] Once a household has decided on a wage, it must supply any quantity of labor service that is demanded at that wage.

A particular household j that is able to re-optimize its wage at t solves the following problem:

$$\max_{W_t(j)} E_t \left\{ \sum_{i=0}^{\infty} (\beta\theta_w)^i \left(U_{j,t+i} + \lambda_{t+i} \frac{W_t(j)\Gamma_{W,t}^i}{P_{X,t+i}} \right) \right\},$$

subject to the labor demand (7) and the updating rule for the nominal wage (9). $U_{j,t+i}$ refers to the utility function of household j in period $t+i$ and λ_{t+i} is the marginal utility of income in period $t+i$, and is given by $\lambda_{t+i} = \beta^{t+i} \exp(\nu_{t+i}) \left(C_{t+i} - hC_{t+i-1}\right)^{-1}$.[6]

2.2 Sector of Home goods

The production and distribution of Home goods is carried out in two stages. In the first stage, wholesalers produce differentiated intermediate Home goods. In the second stage, retailers buy these intermediate goods and combine them to distribute them as final Home

[5] The connection between the headline price index, CPI_t and the core price index, $P_{X,t}$ is formalized below when explaining the aggregate equilibrium.

[6] As mentioned above, consumption is the same across households and, therefore, marginal utility of income only depends on the aggregate consumption and the intertemporal ν_t shock.

goods.

Retailers. Retailers act in a perfectly competitive manner and distribute $Y_{H,t}$ units of the final Home goods according to the following aggregation technology:

$$Y_{H,t} = \left(\int_0^1 \left(Y_{H,t}(z_H)\right)^{1-1/\epsilon_H} dz_H \right)^{\epsilon_H/(\epsilon_H-1)} \tag{10}$$

where $Y_{H,t}(z_H)$ is the number of units of intermediate Home good of type z_H used by the retailers. We assume that there is a continuum of these intermediate Home goods, indexed by $z_H \in [0,1]$. Note that ϵ_H is the elasticity of substitution between the differentiate intermediate Home goods.

Wholesalers. The wholesaler of type z_H produces the differentiated intermediate good, $Y_{H,t}(z_H)$, using the following simple technology that uses only labor as input:

$$Y_{H,t}\left(z_H\right) = A_{H,t} N_{H,t}\left(z_H\right), \tag{11}$$

where $Y_{H,t}\left(z_H\right)$ represents the quantity of a particular variety z_H and $N_{H,t}\left(z_H\right)$ is the labor input utilized. Variable $A_{H,t}$ represents a productivity level in the Home goods sector that is common to all firms and follows an AR(1) process. With this technology the marginal cost is:

$$MC_{H,t} = \frac{W_t}{A_{H,t}}.$$

Notice that the marginal cost depends only on wages and the productivity level, which is equal for all firms. Therefore, the marginal cost is independent from the scale of production of a particular firm.

Price setting. Following Calvo (1983) we assume that only a fraction $1 - \theta_H$ of the wholesalers can reset their prices each period. We assume that a wholesaler that does not receive the signal to adjust optimally its price follows a simple "passive" rule to update the price. In particular, if the wholesaler does not adjust optimally its price between t and $t + i$, then the price it charges in $t + i$ is given by $\Gamma^i_{H,t} P_{H,t}\left(z_H\right)$, where $\Gamma^i_{H,t}$ is a function that describes the updating rule defined as:

$$\Gamma^i_{H,t} = \prod_{j=1}^{i} \left(1 + \pi_{H,t+j-1}\right)^{\chi_H} \left(1 + \bar{\pi}\right)^{1-\chi_H}, \tag{12}$$

where $1 + \pi_{H,t} = \left(P_{H,t}/P_{H,t-1}\right)$, and where again $\bar{\pi}$ corresponds to the inflation target. The parameter χ_H captures the degree of "indexation" whereas $1 - \chi_H$ is the weight of the inflation target in this updating rule. If the firm receives a signal to optimally adjust its price it will choose $P^{op}_{H,t}(z_H)$ to maximize

$$\sum_{i=0}^{\infty} \theta_H^i E_t \left\{ \Lambda_{t,t+i} \frac{\Gamma^i_{H,t} P^{op}_{H,t}(z_H) - MC_{H,t+i}}{P_{X,t+i}} Y_{H,t+i}(z_H) \right\} \exp(\varepsilon_{mh,t}), \tag{13}$$

subject to the demand for variety z_H given by

$$Y_{H,t}(z_H) = \left(\frac{P_{H,t}(z_H)}{P_{H,t}} \right)^{-\epsilon_H} Y_{H,t}, \tag{14}$$

where $\varepsilon_{mh,t}$ is iid (independent and identically distributed) mark-up shock with zero mean and standard deviation σ_{mh}. $\Lambda_{t,t+i}$ is the relevant discount factor between periods t and $t+i$, and is given by $\Lambda_{t,t+i} = \lambda_{t+i}/\lambda_t$.

2.3 Sector of Foreign goods

Like the sector of Home goods, we assume that the production of Foreign goods occurs in two stages. In the first stage, a continuum of wholesalers import Foreign goods and sell them in a differentiated manner to the retailers of Foreign goods. In the second stage, retailers combine these differentiated goods into a final Foreign or imported good, which is consumed by the households.

Retailers. Retailers behave competitively and sell the final Foreign goods by combining intermediate Foreign goods by using the following technology:

$$Y_{F,t} = \left(\int_0^1 (Y_{F,t}(z_F))^{1-1/\epsilon_F} \, dz_F \right)^{\epsilon_F/(\epsilon_F - 1)} \tag{15}$$

where $Y_{F,t}$ is the supply of final Foreign goods, $Y_{F,t}(z_F)$ is the number of units of intermediate imported good of type z_F ($z_F \in [0,1]$), and ϵ_F is the elasticity of substitution between intermediate imported goods. The aggregate price of imported goods is given by:

$$P_{F,t} = \left(\int_0^1 (P_{F,t}(z_F))^{1-\epsilon_F} \, dz_F \right)^{\frac{1}{1-\epsilon_F}}$$

Wholesalers. Each wholesaler of Foreign goods imports from the rest of the world at a given price, $P^*_{F,t}$, in foreign currency. Then, each wholesaler sells its imports as a differentiated imported good, internalizing its market power. The continuum of wholesalers are decomposed in two types. One type has an incomplete exchange rate pass-through in the short-run with a share of α_F and they are denoted by $z_F \in [0, \alpha_F]$. The other type of imported wholesaler has a complete exchange rate pass-through, implying that:

$$P_{F,t}(z_F) = \frac{\epsilon_F}{\epsilon_F - 1} P^*_{F,t} S_t \psi_{F,t} = P^h_{F,t}, \; z_F \in (\alpha_F, 1]$$

where $\psi_{F,t}$ is an additional shock to the price of imported goods with complete exchange rate pass-through and we define the price of this type of imported good by $P^h_{F,t}$ (foreign prices with complete or *high* exchange rate pass-through).

Similarly to the wholesalers of Home intermediate goods, we will assume that wholesalers of Foreign goods with incomplete exchange rate pass-through face a nominal rigidity to choosing their prices in the local currency each period. Formally, each wholesaler of Foreign goods can optimally choose its prices $(P_{F,t}(z_F), z_F \in [0, \alpha_F])$ when it receives a signal, which arrives each period with a Calvo (1983) probability $1-\theta_F$. The optimal choice of $P_{F,t}(z_F), z_F \in [0, \alpha_F]$ faces a iid mark-up shock $(\varepsilon_{mf,t})$ with mean zero and standard deviation σ_{mf}. If the wholesaler does not receive the signal to choose the optimal price, which occurs with probability θ_F, it will adjust the price following a rule that is a weighted average between the inflation target and the past inflation of Foreign goods in domestic currency. In this rule, the weight of the inflation target is given by $1 - \chi_F$ and the weight of the past inflation of Foreign goods is χ_F. The average price of the imported goods with *low* or incomplete exchange rate pass-through is

$$P^l_{F,t} = \left(\frac{1}{\alpha_F} \int_0^{\alpha_F} (P_{F,t}(z_F))^{1-\epsilon_F} dz_F \right)^{\frac{1}{1-\epsilon_F}} \tag{16}$$

which implies that:

$$P_{F,t} = \left(\alpha_F (P^l_{F,t})^{1-\epsilon_F} + (1-\alpha_F)(P^h_{F,t})^{1-\epsilon_F} \right)^{\frac{1}{1-\epsilon_F}} \tag{17}$$

2.4 Commodities and foreign sector

We assume that the production of commodities requires no inputs and follows a stochastic endowment. The endowment of commodity is denoted by $Y_{CO,t}$ and is completely exported. The exogenous evolution for $Y_{CO,t}$ is given by a log-linear autoregressive process of order 1.

For commodity prices, the law of one price holds. Hence, the domestic prices of commodities are given by the following expression:

$$P_{CO,t} = S_t P^*_{CO,t} \tag{18}$$

where $P^*_{CO,t}$ is the foreign currency price of commodity CO. The real foreign price of the commodity, $P^*_{CO,t}/P^*_{F,t}$ is assumed to follow a log-linear autoregressive process of order 1.

The foreign demand for Home goods is given by the following expression:

$$C^*_{H,t} = \gamma^* \left(\frac{P^*_{H,t}}{P^*_{F,t}} \right)^{-\eta^*} Y^*_t D^*_{H,t}, \tag{19}$$

where Y_t^* is the relevant foreign GDP for the Uruguayan economy, γ^* corresponds to the share of Home goods in the consumption basket of foreign agents, η^* is the price elasticity of the foreign demand for Home goods, and $D_{H,t}^*$ is a residual in this foreign demand equation and it can be interpreted as an export shock. $D_{H,t}^*$ will be modelled as an AR(1) process. We assume that domestic firms cannot price discriminate across markets. Therefore, the law of one price holds for final Home goods sold abroad, $P_{H,t}^* = P_{H,t}/S_t$.

The real exchange rate is defined as the relative price of the foreign consumption basket, $P_{F,t}^*$, relative to the price of the total CPI basket:

$$RER_t \equiv \frac{S_t P_{F,t}^*}{CPI_t}. \tag{20}$$

Foreign inflation expressed in foreign currency (US dollars in the case of Uruguay) is defined as $\pi^* = P_{F,t}^*/P_{F,t-1}^* - 1$. We will assume that π^* follows an AR(1) process.

2.5 Monetary policy under perfect and imperfect credibility

A feature that distinguishes the Uruguayan monetary policy from what is usually carried out in the rest of the inflation targeters is that it has changed the intermediate target of the regime twice throughout the sample period. Nevertheless, we will assume that the instrument that summarizes the stance of monetary policy for the whole sample is the short-term interest rate. Thus, according to the specified Taylor rule, the short-run interest rate responds to inflation rate deviations with respect to the inflation target, the GDP growth rate gap with respect to the balanced growth path and the nominal depreciation rate gap with respect to its steady state value. Finally, the rule allows for smoothing of the short-term interest rate and a monetary disturbance or surprise term ($e_{R,t}$). Formally, the monetary policy rule is specified as a Taylor-type rule:

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R} \left(\left(\frac{1+\pi_{X,t}}{1+\bar{\pi}}\right)^{\alpha_\pi} \left(\frac{Y_t/Y_{t-1}}{1+\bar{\gamma}_Y}\right)^{\alpha_y} \left(\frac{S_t/S_{t-1}}{1+\bar{\gamma}_S}\right)^{\alpha_S}\right)^{1-\rho_R} \exp(e_{R,t}) \tag{21}$$

where $\pi_{X,t} = P_{X,t}/P_{X,t-1} - 1$ is core inflation and Y_t is total real GDP. $e_{R,t}$ is a non-systematic deviation of the monetary policy rate from the systematic rule, which is independent and identically distributed with mean zero and variance σ_R^2. $\bar{R}$, $\bar{\gamma}_Y$ and $\bar{\gamma}_S$ are the steady state values for the interest rate, the real GDP growth and the exchange rate depreciation. Hence, the monetary policy rule makes a balance to stabilize simultaneously three variables: core inflation, GDP growth, and exchange rate depreciation. Parameters α_π, α_y, and α_S are the weights in the rule to stabilize each of the three target variables. Finally, ρ_R defines the degree of inertia or smoothing in the monetary policy rate.

One innovation of the model is the possibility to incorporate imperfect credibility in the monetary policy. We first explain a situation where monetary policy has full credibility. We then explain the main deviation from this first case when monetary policy has imperfect credibility.

Perfect credibility. We will assume that when monetary policy has perfect credibility the perceived monetary policy rule by the private agents is exactly the same as the actual rule (21). This assumption will result in an equal path for the expected monetary policy rate by the private agents and the future path implied by the actual monetary policy rule.

Imperfect Credibility. Under imperfect credibility, private agents use the same systematic reaction given by (21), but they believe that the medium term inflation target can change instead of being constant. In particular, we assume that the perceived monetary rule is given by:

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R} \left(\left(\frac{1+\pi_{X,t}}{1+\bar{\pi}_t}\right)^{\alpha_\pi} \left(\frac{Y_t/Y_{t-1}}{1+\bar{\gamma}_Y}\right)^{\alpha_y} \left(\frac{S_t/S_{t-1}}{1+\bar{\gamma}_S}\right)^{\alpha_S} \right)^{1-\rho_R} \exp(e_{R,t}) \tag{22}$$

where $\bar{\pi}_t$ is the perceived inflation target, which can change over time due to shocks. Although the actual monetary policy rule is not changing the inflation target, private agents believe that the central bank might want to adjust the inflation target in response to shocks that generate a temporary deviation of inflation from its target. The presence of $\bar{\pi}_t$ and $e_{R,t}$ implies that the private agents do not know if the deviation of the monetary policy rate from its systematic behavior is due to changes in $\bar{\pi}_t$ or in $e_{R,t}$.

Importantly, the expected monetary policy path is critical to determine the effects of different shocks in the economy. However, if private agents cannot observe whether the deviation from the monetary policy rule is coming from $\bar{\pi}_t$ or $e_{R,t}$, they will expect a different path for the monetary policy rate in comparison to the one determined by the actual monetary policy rule given in (21). This expectations channel will affect the dynamics of the variables, modifying the degree of propagation of the shocks to the exchange rate and inflation. Thus, private agents believe that the central bank has intentions to change the medium term inflation target in response to shocks that affect the exchange rate despite the fact that the central bank is not doing so. In order to characterize this possibility, we will assume that the perceived process for the inflation target is:

$$\bar{\pi}_t = (1-\rho_{\bar{\pi}})\bar{\pi} + \rho_{\bar{\pi}}\bar{\pi}_{t-1} + \sum_{j=1}^{k}(1-\omega_{j,t})a_j\varepsilon_{j,t} + \varepsilon_{\bar{\pi},t} \tag{23}$$

where $\{\varepsilon_{j,t}\}_{j=1}^{k}$ is the list of shocks that affect exogenous variables such as foreign interest rate, sovereign spread, foreign demand, commodity prices, the intertemporal disturbance, and so on.[7]

In expression (23) $w_{j,t}$ is the probability assigned by the private agents to a case where the inflation target is constant in response to a shock in $\varepsilon_{j,t}$, whereas $1 - w_{j,t}$ is the probability assigned by the private agents to a change in the inflation target. Parameter μ defines the unconditional probability across all shocks assigned by the private sector to a constant inflation target. Instead of calibrating μ, it is estimated together with the rest of parameters in the imperfect credibility case. Coefficient a_j is a parameter that determines the magnitude of that perceived change for the specific shock j. $\rho_{\bar{\pi}}$ is the persistence in the perceived changes in the inflation target and $\varepsilon_{\bar{\pi},t}$ is an additional shock to the inflation target. It is worth noting that the systematic reaction of the monetary policy rate in (22) is equivalent to the one in (21). Nevertheless, the deviations from the systematic part can be attributed to either $e_{R,t}$ or to perceived changes in $\bar{\pi}_t$. The inability to observe explicitly that the inflation target is not changing under imperfect credibility affects the expectation formation despite the fact that the central bank is not actually adjusting the inflation target.

It is important to note that we model imperfect credibility following closely Erceg and Levin (2003). A similar approach to analyze other macroeconomic issues with imperfect credibility is followed by Adler et al. (2016), De Michelis and Iacoviello (2016), and Lemoine and Lindé (2016). In our case, when a shock $\varepsilon_{j,t}$ hits the economy, that depreciates the currency, agents believe that the central bank can behave in two manners. In one case, private agents think that the central bank allows a short-term depreciation and there is no adjustment in the inflation target. In the other case, private agents believe that the central bank is willing to adjust upward the inflation target in response to $\varepsilon_{j,t}$ (when $a_j > 0$). Using (22) the deviation of the monetary policy rate from its systematic behavior can be written in log-linear form as:

$$dev_{mp,t} = e_{R,t} - (1-\rho_R)\alpha_\pi(\bar{\pi}_t - \bar{\pi}) = e_{R,t} - (1-\rho_R)\alpha_\pi \left(\rho_{\bar{\pi}}(\bar{\pi}_{t-1} - \bar{\pi}) + \sum_{j=1}^{k}(1-\omega_{j,t})a_j\varepsilon_{j,t} + \varepsilon_{\bar{\pi},t} \right)$$

Under imperfect credibility, agents will use a Bayesian process to infer over time the value of $e_{R,t}$ and ω_{j_t} based on the observation of $dev_{mp,t}$ and the shock $\varepsilon_{j,t}$. We will interpret the credibility problem as follows. The lower the value for $\omega_{j,t}$ inferred by the agents, the less credible is the monetary policy in having the expected path of monetary policy determined by the systematic behavior in response to shock $\varepsilon_{j,t}$. In the extreme, when $\omega_{j,t} = 0$, the agents believe that the inflation target is always changing a magnitude a_j in response to shock $\varepsilon_{j,t}$.

[7] Below in section 3, we will specify which shocks have effect in the perceived inflation target under imperfect credibility.

In order to implement the estimation of the model, we create the following two auxiliary variables for each shock with potential effect in the inflation target: $\hat{\varepsilon}_{j,t}$ and $\tilde{\varepsilon}_{j,t}$. We impose that $\varepsilon_{j,t} = \hat{\varepsilon}_{j,t} + \tilde{\varepsilon}_{j,t}$ and that $\hat{\varepsilon}_{j,t}$ and $\tilde{\varepsilon}_{j,t}$ are uncorrelated. We assume that $\hat{\varepsilon}_{j,t}$ corresponds to the changes in $\varepsilon_{j,t}$ conditional on $\omega_{j,t} = 1$ and $\tilde{\varepsilon}_{j,t}$ is attributed to changes in the same shock conditional on $\omega_{j,t} = 0$. With this notation, the unconditional probability of change in the inflation target in response to shock ε_t is $var(\hat{\varepsilon}_{j,t})/(var(\hat{\varepsilon}_{j,t}) + var(\tilde{\varepsilon}_{j,t}))$ and, therefore, $\omega_{j,t}$ conditional on the decomposition of shock $\varepsilon_{j,t}$ in t will be defined as $\hat{\varepsilon}^2_{j,t}/(\hat{\varepsilon}^2_{j,t} + \tilde{\varepsilon}^2_{j,t})$. Accordingly, parameter μ determines this unconditional probability for all shocks ($\mu = var(\hat{\varepsilon}_{j,t})/(var(\hat{\varepsilon}_{j,t}) + var(\tilde{\varepsilon}_{j,t})), \forall j$). In the estimation of the model under imperfect credibility, we will make a bayesian inference about $\bar{\pi}_t$, $\hat{\varepsilon}_{j,t}$, $\tilde{\varepsilon}_{j,t}$, $e_{R,t}$, and $\varepsilon_{\bar{\pi},t}$. More details on how this mechanism can be implemented in a DSGE model can be found in Adler et al. (2016).

2.6 Aggregate Equilibrium

There is no public spending and government transfers all seignorage revenues to households. Thus, the government budget constraint is simply given by:

$$\int \frac{\mathcal{M}_{t+1}(j) - \mathcal{M}_t(j)}{P_t} dj - \int T_t(j)\, dj = 0. \tag{24}$$

The equilibrium for the domestic Bonds, Home goods, Foreign goods and the labor market implies:

$$\begin{array}{l} Y_{H,t} = C_{H,t} + C^*_{H,t}, \qquad Y_{F,t} = C_{F,t}, \qquad , \qquad \int_0^1 B_t(j)dj = 0 \\ \left(\int_0^1 N_t(j)^{\frac{\epsilon_L - 1}{\epsilon_L}} dj \right)^{\frac{\epsilon_L}{\epsilon_L - 1}} = N_t = N_{H,t} = \int_0^1 N_{H,t}(z_H) dz_H \end{array} \tag{25}$$

Combining these equilibrium conditions, the budget constraint of the government and the aggregate budget constraint of households, we obtain an expression for the aggregate accumulation of international bonds

$$\frac{S_t B^*_t}{R^*_t \Theta(B^*_t)} = S_t B^*_{t-1} + P_{H,t} C^*_{H,t} + P_{CO,t} Y_{CO,t} - S_t P^*_{F,t} C_{F,t}, \tag{26}$$

Then, total GDP –at current prices– satisfies the following relationship:

$$P_{Y,t} Y_t = P_{X,t} C_t + P_{H,t} C^*_{H,t} + P_{CO,t} Y_{CO,t} - S_t P^*_{F,t} C_{F,t}, \tag{27}$$

where $P_{Y,t}$ denotes the implicit output deflator. Total real GDP, Y_t, is defined using this last expression valued at the steady state price indexes.

Headline price index (CPI_t) is constructed adding the volatile components such as perishable fruits and vegetables and regulated prices ($P_{NX,t}$) to our measure of core price index, $P_{X,t}$:

$$CPI_t = (P_{X,t})^{1-\gamma_C} (P_{NX,t})^{\gamma_C} \tag{28}$$

where γ_C is the weight of perishable fruits and vegetables and regulated prices in the headline CPI. For simplicity, we will assume that the relative price of non-core items to the headline CPI is an AR(1) process:

$$\ln(\frac{P_{NX,t}}{CPI_t}) = (1-\rho_{NX})\ln(\frac{\bar{P}_{NX,t}}{C\bar{P}I}) + \rho_{NX}\ln(\frac{P_{NX,t-1}}{CPI_{t-1}}) + \varepsilon_{NX,t} \tag{29}$$

where $\varepsilon_{NX,t}$ is an iid shock with zero mean and variance σ^2_{NX} and $\frac{\bar{P}_{NX,t}}{C\bar{P}I}$ is the steady state relative price. Since we use market inflation expectations in the estimation of the model, we define the four quarters ahead headline (year-to-year) inflation expectation as:

$$\pi^e_{t+4|t} = E_t[\pi_{t+1} + \pi_{t+2} + \pi_{t+3} + \pi_{t+4}] + \varepsilon_{\pi^e,t} \tag{30}$$

where $\pi_t = CPI_t/CPI_{t-1} - 1$ and $\varepsilon_{\pi^e,t}$ is an iid shock with zero mean and standard deviation of 0.1 percent. Thus, we allow for a small deviation from the inferred inflation expectation in the model and the observable inflation expectation in the data.

3 Model Estimation

Using a set of observable data, including private sector inflation expectations, we will estimate the parameters of the model with Bayesian techniques. We will estimate two versions of the model. In one version, monetary policy has perfect credibility in keeping invariant the inflation target in response to shocks ($\omega_{j,t} = 1, \forall j, t$). In the other version, we will assume that monetary policy faces a credibility issue in its willingness to hold the inflation target constant. Under this specification, one important ingredient is the estimation of the parameters associated to the imperfect credibility specification, namely, μ, a_j and the Bayesian inference for $\omega_{j,t}$ for each shock hitting the model economy.

This section is organized in the following manner. First, we describe the observable variables used for the estimation. Second, we present the calibration of some parameters that will be kept fixed in the estimation and the priors for the estimated parameters. Finally, we present the posterior estimation of parameters under perfect and imperfect credibility.

3.1 Observable variables

The model is estimated using Uruguayan series at quarterly frequency, using a sample of 62 observations between 2005Q2 and 2020Q3. The model includes 65 endogenous and 23 exogenous variables. For the estimation of the model, 14 observable variables were selected, which are detailed in Table 1. To have discipline in the estimation of the possibility of the imperfect credibility mechanism, inflation expectations data is added as an observable variable. These data come from the Central Bank of Uruguay professionals survey. There is also a firm survey, but it started in 2009, so the time period would be shortened. The series were seasonally adjusted using the X-13-ARIMA filter and expressed in logs.

The commodity price is expressed in dollars relative to the foreign CPI and as deviation with respect to its mean. The rest of variables are used as the quarterly variation. The variations are also expressed as deviation from their means, except in the case of headline inflation, CPI components and inflation expectations, which are expressed as deviation from an annual 5 percent variation, which corresponds to the midpoint of the 3-7 percent target range set by the Central Bank of Uruguay.

Table 1: Observable variables

Variable	Description	Source
Y_t	Real Gross Domestic Product (base 2005)	BCU
R_t	Daily interest rate for overnight interbank loans	BCU
ξ_t	Uruguayan country risk (UBI)	Bloomberg
R_t^{US}	Risk free interest rate (Fed Funds Rate)	Bloomberg
Y_t^*	Relevant external GDP, weighted by previous year exports	BCU
$\pi_{F,t}^*$	Relevant international prices for Uruguay	BCU
$\pi_{H,t}$	Inflation of the Home goods (non tradables)	BCU, based on INE
$\pi_{F,t}$	Inflation of the tradable goods	BCU, based on INE
S_t	Nominal exchange rate	BCU
π_t	Headline inflation	INE
$\pi_{t+4\|t}^e$	Expected inflation (eight quarters ahead)	BCU
W_t	Average private wage index (after taxes)	INE
$\pi_{F,t}^l$	Inflation of imported goods with low or incomplete ERPT	BCU, based on INE
$P_{CO,t}^*/P_{F,t}^*$	International price of the commodity (real)	BCU

3.2 Calibrated parameters and priors for estimated parameters

A first step for the bayesian estimation consists in calibrating a set of parameters that will remain unaltered in the estimation. Most of these parameters are associated with the steady state values of the variables in the model and, therefore, they are calibrated so as to adapt separately to the macroeconomic statistics of the Uruguayan economy.

The calibrated parameters and their values are shown in table 2. The subjective discount factor is set at a value of 0.9975 in quarterly frequency. The share of core items and non-core items in the CPI is respectively, 72 and 28 percent, implying $\gamma_C = 0.28$. Items classified as tradable within the core CPI are considered the foreign goods, having a weight in the total CPI of 35 percent and making α_C close to 0.49. Estimations of the exchange rate pass-through (ERPT) at the product level suggest that two-thirds of tradable products in the CPI basket has an incomplete ERPT and we set $\alpha_F = 2/3$.[8] Elasticities of substitution in the sector of home and foreign goods and in the labor market are all set in 11 ($\epsilon_H = \epsilon_F = \epsilon_L = 11$). The share of commodity in total GDP is 10 percent and the ratio of net exports-to-GDP is set in 1 percent. The upward sloping supply of external fund (ϱ) is assumed to have a very elastic sensitivity to net external debt as it has been estimated in Basal et al. (2016). Using the constructed series for R_t^{US}, ξ_t, variable $\psi_{F,t}$, and $P_{CO,t}^*/P_t^*$, we estimate an AR(1) processes for each series to calibrate the persistence and standard deviations of the shocks to these variables.

Table 2: Calibrated parameters

Parameter	Value	Comments
β	0.9975	
α_C	0.49	F is 35% and H is 37%
γ_C	0.28	Non-core CPI has a weight of 28%
α_F	0.67	Share of imported good with low ERPT
ϵ_H and ϵ_F	11	Average mark-up of price above costs of 10%
ϵ_L	11	Average mark-up of 10% of wage above $-U_N/U_C$
ϱ	0.01	Assume very elastic supply of external borrowing
$\frac{Y_{CO}}{GDP}$	0.10	Weight of commodities in total GDP is around 10%
$\frac{X-M}{GDP}$	0.01	Average trade balance as percentage of GDP
$\rho_{R_{US}}$	0.9754	AR(1) estimation before the Bayesian procedure
ρ_ξ	0.7623	AR(1) estimation before the Bayesian procedure
ρ_{π^*}	0.2980	AR(1) estimation outside the Bayesian estimation
ρ_{ψ_F}	0.9668	AR(1) estimation outside the Bayesian estimation
$\rho_{p_{CO}^*}$	0.8839	AR(1) estimation before the Bayesian procedure
$\sigma_{R_{US}}$	0.08%	AR(1) estimation before the Bayesian procedure
σ_ξ	0.14%	AR(1) estimation before the Bayesian procedure
σ_{π^*}	3.3774%	AR(1) estimation before the Bayesian procedure
σ_{ψ_F}	2.58%	AR(1) estimation before the Bayesian procedure
$\sigma_{p_{CO}^*}$	6.98%	AR(1) estimation before the Bayesian procedure
$\sigma_{\bar{\pi}}$	0.1%	Assumed a low value
σ_{π^e}	0.1%	Assumed a low value

Table 3 summarizes the list of exogenous variables included in the model that are ex-

[8]We thank Margarita Güenaga for sharing her estimations of the ERPT at the product level.

posed to shocks. In this table, we also specify which shocks to these exogenous variables are considered to affect the perceived inflation target under the case of imperfect credibility. It is important to note that we have modelled that most of the shocks can potentially affect the perceived inflation target. Finally, in table 3 we also describe which shocks have a positive or negative coefficient a_j. This choice was based on the effect of the particular shock on the exchange rate under the model with perfect credibility. If the particular shock j implies a depreciation in the exchange rate under perfect credibility, we assume a positive support for the prior of the coefficient a_j. In contrast, if the particular shock j appreciates the exchange rate, we assume a negative support for the prior for a_j. For convenience, in these last cases, we set a positive prior for $-a_j$. Using the equation for the perceived inflation target (23), the shocks $\varepsilon_{j,t}$ that can have $a_j \neq 0$ under imperfect credibility are $j = \nu$, l_s, R^{US}, ξ, ζ, π^*, a_H, ψ_F, p^*_{CO}, Y_{CO}, Y^*, D^*_H, and p_{NX}.

Table 3: List of exogenous variables and implied parameters

Exogenous variables	Description	Persistence	Standard deviation	a_j Imp. Cred.
ν_t	Intertemporal disturbance	ρ_ν, estimated	σ_ν, estimated	$a_\nu < 0$
$l_{s,t}$	Labor supply shock	ρ_{l_s}, estimated	σ_{l_s}, estimated	$a_{l_s} < 0$
R_t^{US}	Risk free interest rate	$\rho_{R_{US}}$, calibrated	$\sigma_{R_{US}}$, calibrated	$a_{R_{US}} > 0$
ξ_t	Uruguayan country risk	ρ_ξ, calibrated	σ_ξ, calibrated	$a_\xi > 0$
ζ_t	Exchange rate risk	ρ_ζ, estimated	σ_ζ, estimated	$a_\zeta > 0$
π_t^*	Foreign inflation	ρ_{π^*}, estimated	σ_{π^*}, estimated	$a_{\pi^*} < 0$
$a_{H,t}$	Productivity shock in sector H	ρ_{a_H}, estimated	σ_{a_H}, estimated	$a_{a_H} > 0$
$\psi_{F,t}$	Additional factor for $P_{F,t}^h$	ρ_{ψ_F}, estimated	σ_{ψ_F}, estimated	$a_{\psi_F} > 0$
$P^*_{CO,t}/P^*_{F,t}$	Commodity price	$\rho_{p^*_{CO}}$, calibrated	$\sigma_{p^*_{CO}}$, calibrated	$a_{p^*_{CO}} < 0$
$Y_{CO,t}$	Commodity production	$\rho_{Y_{CO}}$, estimated	$\sigma_{Y_{CO}}$, estimated	$a_{Y_{CO}} < 0$
Y_t^*	Foreign demand	ρ_{Y^*}, estimated	σ_{Y^*}, estimated	$a_{Y^*} < 0$
$P_{NX,t}/CPI_t$	Relative price of non-core prices	ρ_{NX}, estimated	σ_{NX}, estimated	$a_{NX} < 0$
$D^*_{H,t}$	Export shock	ρ_{DH^*}, estimated	σ_{DH^*}, estimated	$a_{DH^*} < 0$
$\varepsilon_{mh,t}$	Markup shock in $P_{H,t}$	None	σ_{mcH}, estimated	None
$\varepsilon_{mf,t}$	Markup shock in $P_{F,t}^l$	None	σ_{mcF}, estimated	None
$e_{R,t}$	Monetary policy shock	None	σ_{e_R}, estimated	None
$\varepsilon_{\bar{\pi},t}$	Exogenous shock to $\bar{\pi}_t$	None	$\sigma_{\bar{\pi}}$, calibrated	None
$\varepsilon_{\pi^e,t}$	Inflation expectation shock	None	σ_{π^e}, calibrated	None

Non-calibrated parameters will be estimated using Bayesian methods. The Bayesian method is described in detail by Schorfheide (2000) and Fernández-Villaverde and Rubio-Ramírez (2007) and it has been used extensively to estimate this type of models in advanced and emerging economies. The priors of the parameters under perfect credibility model are presented in table 4. For the imperfect credibility model we use the same priors as in table 4. Additional estimated parameters in the imperfect credibility model have priors described in table 5.

Table 4: Priors for estimated parameters

Parameter	Description	Prior		
		Shape	Mean	S.D.
σ_L	Inverse of the elasticity of labor supply	inverse gamma	1.00	0.20
σ	Intertemporal substitution elasticity	inverse gamma	1.00	0.20
h	Habit in consumption	beta	0.70	0.10
η_C	Substitution elasticity between goods H and F	inverse gamma	1.00	0.20
θ_H	Probability of not adjusting prices (Calvo)	beta	0.75	0.10
χ_H	Indexation to past inflation in sector H	beta	0.50	0.10
θ_F	Probability of not adjusting prices (Calvo)	beta	0.75	0.10
χ_F	Indexation to past inflation in sector F	beta	0.50	0.10
θ_w	Probability of not adjusting prices (Calvo)	beta	0.75	0.10
χ_w	Indexation to past inflation in wages	beta	0.50	0.10
η^*	Price elasticity of external demand for goods H	inverse gamma	0.50	0.20
ρ_R	Persistence in Taylor Rule (TR)	beta	0.80	0.15
α_π	Inflation reaction in TR	normal	1.50	0.20
α_y	GDP reaction in TR	normal	0.30	0.15
α_S	Exchange rate reaction in TR	normal	0	1
ρ_ζ	Persistence of country risk shock	beta	0.70	0.10
ρ_ζ	Persistence of international prices	beta	0.70	0.10
ρ_{a_H}	Persistence of productivity shock	beta	0.70	0.10
ρ_ν	Persistence of consumption shock	beta	0.70	0.10
ρ_{y^*}	Persistence of trade partner GDP shock	beta	0.70	0.10
$\rho_{y_{CO}}$	Persistence of commodities production shock	beta	0.70	0.10
ρ_{NX}	Persistence of non-core price shock	beta	0.70	0.10
ρ_{DH^*}	Persistence of residual of foreign demand	beta	0.70	0.10
ρ_{l_s}	Persistence of labour supply shock	beta	0.70	0.10
σ_ζ	Country risk shock s.d.	inverse gamma	1.00	0.50%
σ_ν	Consumption shock s.d.	inverse gamma	1.00	0.25%
σ_{a_H}	Productivity shock s.d.	inverse gamma	1.00	0.25%
$\sigma_{Y_{CO}}$	Commodities production shock s.d.	inverse gamma	1.00	0.25%
σ_{y^*}	Commercial partners income shock s.d.	inverse gamma	1.00	0.25%

Continued on next page

Table 4 – continued from previous page

Parameter	Description	Prior		
		Shape	Mean	S.D.
σ_{e_R}	Monetary policy shock s.d.	inverse gamma	0.30	0.10%
σ_{NX}	Non-core price shock s.d.	inverse gamma	1.00	0.50%
σ_{DH^*}	External demand shock s.d.	inverse gamma	1.00	0.50%
σ_{l_s}	Labour supply shock s.d.	inverse gamma	1.00	0.50%
σ_{mh}	mark-up shock s.d in sector H	inverse gamma	1.00	0.50%
σ_{mf}	mark-up shock s.d in sector F	inverse gamma	1.00	0.50%

Table 5: Priors for additional parameters under imperfect credibility

Parameter	Description	Prior		
		Shape	Mean	S.D.
μ	Uncond. prob. of a constant inflation target	beta	0.50	0.10
$\|a_{R_US}\|$	Effect of R^{US} on the perceived inflation target	inverse gamma	1.00	0.50
$\|a_{\pi^*}\|$	Effect of π^* on the perceived inflation target	inverse gamma	1.00	0.50
$\|a_\xi\|$	Effect of ξ on the perceived inflation target	inverse gamma	1.00	0.50
$\|a_\zeta\|$	Effect of ζ on the perceived inflation target	inverse gamma	1.00	0.50
$\|a_{Y^*}\|$	Effect of Y^* on the perceived inflation target	inverse gamma	1.00	0.50
$\|a_{NX}\|$	Effect of P_{NX} on the perceived inflation target	inverse gamma	1.00	0.50
$\|a_{a_H}\|$	Effect of $A_{H,t}$ on the perceived inflation target	inverse gamma	1.00	0.50
$\|a_\nu\|$	Effect of ν_t on the perceived inflation target	inverse gamma	1.00	0.50
$\|a_{Y_{CO}}\|$	Effect of $Y_{CO,t}$ on the perceived inflation target	inverse gamma	1.00	0.50
$\|a_{p^*_{CO}}\|$	Effect of $P^*_{CO,t}$ on the perceived inflation target	inverse gamma	1.00	0.50
$\|a_{l_s}\|$	Effect of $l_{s,t}$ on the perceived inflation target	inverse gamma	1.00	0.50
$\|a_{\psi_F}\|$	Effect of $\psi_{F,t}$ on the perceived inflation target	inverse gamma	1.00	0.50
$\|a_{DH^*}\|$	Effect of $D^*_{H,t}$ on the perceived inflation target	inverse gamma	1.00	0.50
$\rho_{\bar{\pi}}$	Persistence of changes in the perceived inflation target	beta	0.70	0.10

Note: $|\cdot|$ denotes absolute value.

3.3 Estimation under perfect and imperfect credibility

The two versions of the model are estimated using a Bayesian approach, which derives the posterior probability distribution conditional on the model and the data, using a combination of a *priori* distribution of the parameters and the maximum likelihood function of the model, which is evaluated using the Kalman filter. Then, the Metropolis Markov chain Monte Carlo (MCMC) algorithm is used to generate random samples of the posterior distribution to obtain approximate values of the moments of the distribution (mean, standard deviation, and confidence intervals), for the parameters of interest.[9] Formally, the parameters are estimated numerically using the MCMC algorithm, with one block of 500,000 iterations, of which the first 20% are discarded. Table 6 presents the posterior estimation of parameters under perfect credibility, whereas table 7 does the same under imperfect credibility.

Table 6: Posteriors of the estimated parameters under perfect credibility

Parameter	Posterior		
	Mode	90% HPD interval	S.D.
σ_L	0.93	[0.70 , 1.34]	0.17
σ	1.19	[0.85 , 1.84]	0.26
h	0.76	[0.69 , 0.87]	0.06
η_C	0.85	[0.65 , 1.10]	0.13
θ_H	0.96	[0.95 , 0.97]	0.01
χ_H	0.33	[0.23 , 0.46]	0.07
θ_F	0.91	[0.89 , 0.93]	0.01
χ_F	0.42	[0.29 , 0.54]	0.08
θ_w	0.75	[0.64 , 0.86]	0.07
χ_w	0.51	[0.34 , 0.68]	0.11
η^*	0.38	[0.25 , 0.54]	0.09
ρ_R	0.71	[0.66 , 0.76]	0.03
α_π	1.47	[1.28 , 1.69]	0.12
α_y	0.42	[0.26 , 0.60]	0.10
α_S	0.18	[0.10 , 0.29]	0.05
ρ_ζ	0.65	[0.55 , 0.71]	0.05
ρ_{a_H}	0.72	[0.53 , 0.87]	0.11
ρ_ν	0.92	[0.86 , 0.95]	0.02
ρ_{y^*}	0.90	[0.82 , 0.96]	0.05
$\rho_{y_{CO}}$	0.72	[0.54 , 0.87]	0.11
ρ_{NX}	0.95	[0.93 , 0.97]	0.01
ρ_{DH^*}	0.98	[0.96 , 0.99]	0.01

Continued on next page

[9]More details on the implementation of the Bayesian Estimation in DSGE models can be found, for instance, in Schorfheide (2000) and Fernández-Villaverde and Rubio-Ramírez (2007).

Table 6 – continued from previous page

Parameter	Posterior		
	Mode	90% HPD interval	S.D.
ρ_{l_s}	0.45	[0.29 , 0.60]	0.10
σ_ζ	1.05	[0.85 , 1.34]	0.14
σ_ν	5.88	[3.62 , 9.11]	1.51
σ_{a_H}	0.88	[0.62 , 1.38]	0.19
$\sigma_{Y_{CO}}$	0.88	[0.62 , 1.40]	0.19
σ_{y^*}	1.40	[1.23 , 1.63]	0.12
σ_{e_R}	0.65	[0.56 , 0.80]	0.07
σ_{NX}	1.09	[0.95 , 1.29]	0.10
σ_{DH^*}	4.25	[3.68 , 5.28]	0.45
σ_{l_s}	1.38	[1.09 , 1.71]	0.18
σ_{mh}	1.26	[0.83 , 2.33]	0.35
σ_{mf}	0.87	[0.56 , 1.38]	0.22
Log data density		2770.27	

Table 7: Posteriors of the estimated parameters under imperfect credibility

Parameter	Posterior		
	Mode	90% HPD interval	S.D.
σ_L	0.90	[0.69 , 1.28]	0.16
σ	0.82	[0.67 , 1.10]	0.11
h	0.75	[0.62 , 0.88]	0.09
η_C	0.71	[0.57 , 0.86]	0.09
θ_H	0.96	[0.95 , 0.97]	0.01
χ_H	0.32	[0.22 , 0.45]	0.07
θ_F	0.95	[0.93 , 0.97]	0.01
χ_F	0.39	[0.27 , 0.50]	0.08
θ_w	0.78	[0.67 , 0.86]	0.06
χ_w	0.49	[0.33 , 0.65]	0.11
η^*	0.26	[0.20 , 0.34]	0.04
ρ_R	0.91	[0.89 , 0.94]	0.02
α_π	1.37	[1.05 , 1.57]	0.20
α_y	0.46	[0.21 , 0.70]	0.15
α_S	2.95	[2.45 , 4.23]	0.52

Continued on next page

Table 7 – continued from previous page

Parameter	Posterior		
	Mode	90% HPD interval	S.D.
ρ_ζ	0.70	[0.59 , 0.79]	0.06
ρ_{a_H}	0.72	[0.55 , 0.86]	0.11
ρ_ν	0.72	[0.55 , 0.87]	0.11
ρ_{y^*}	0.92	[0.84 , 0.96]	0.04
$\rho_{y_{CO}}$	0.72	[0.54 , 0.86]	0.11
ρ_{NX}	0.81	[0.77 , 0.85]	0.03
ρ_{DH^*}	0.89	[0.76 , 0.95]	0.05
ρ_{l_s}	0.46	[0.30 , 0.61]	0.10
σ_ζ	0.91	[0.75 , 1.16]	0.13
σ_ν	0.88	[0.63 , 1.37]	0.19
σ_{a_H}	0.88	[0.63 , 1.35]	0.19
$\sigma_{Y_{CO}}$	0.88	[0.64 , 1.37]	0.19
σ_{y^*}	1.42	[1.25 , 1.65]	0.12
σ_{e_R}	1.09	[0.88 , 1.49]	0.16
σ_{NX}	0.94	[0.83 , 1.11]	0.08
σ_{DH^*}	4.13	[3.54 , 4.90]	0.40
σ_{l_s}	1.35	[1.09 , 1.70]	0.19
σ_{mh}	1.18	[0.83 , 2.17]	0.31
σ_{mf}	2.25	[1.13 , 5.74]	0.93
μ	0.43	[0.32 , 0.58]	0.09
$\lvert a_{R_US}\rvert$	0.53	[0.40 , 0.84]	0.10
$\lvert a_{\pi^*}\rvert$	1.02	[0.56 , 2.01]	0.35
$\lvert a_\xi\rvert$	0.82	[0.50 , 1.45]	0.24
$\lvert a_\zeta\rvert$	0.63	[0.44 , 1.04]	0.15
$\lvert a_{Y^*}\rvert$	0.58	[0.42 , 0.95]	0.13
$\lvert a_{NX}\rvert$	1.06	[0.62 , 1.86]	0.33
$\lvert a_{a_H}\rvert$	0.62	[0.44 , 1.04]	0.15
$\lvert a_\nu\rvert$	0.62	[0.45 , 1.08]	0.15
$\lvert a_{Y_{CO}}\rvert$	0.62	[0.43 , 1.07]	0.15
$\lvert a_{p^*_{CO}}\rvert$	0.50	[0.38 , 0.79]	0.10
$\lvert a_{l_s}\rvert$	0.78	[0.51 , 1.38]	0.21
$\lvert a_{\psi_F}\rvert$	1.03	[0.59 , 1.83]	0.31
$\lvert a_{DH^*}\rvert$	0.58	[0.42 , 0.96]	0.13
$\rho_{\bar{\pi}}$	0.80	[0.73 , 0.85]	0.04
Log data density		2777.23	

4 Estimation analysis and applications

In this section we use the estimated model to understand the connection of the inflation dynamics with the exchange rate movements and how this is related with the specific shock and the monetary policy credibility. In the first subsection, we focus on the role of the exchange rate stabilization and monetary policy credibility, analyzing the empirical fit of alternative versions of the model and the inferred probability of perfect credibility. In the second subsection, we compute the conditional ERPT depending on the specific shock and monetary policy credibility.[10]

4.1 The role of exchange rate stabilization and imperfect credibility

We compare four specifications of the model: the two specifications from previous sections (namely, a model with imperfect credibility in the inflation target (1) and a model with perfect credibility (2)), both of which estimate a monetary policy rule in which the interest rate depends, among others, on the movements of the nominal exchange rate; and two new alternatives, in which we calibrate the response of the monetary policy rate to the nominal exchange rate to zero.

Table 8: Alternative specifications of the model - mode and log data density

	Imperf. Cred (1)	Perf. Cred (2)	Perf. Cred (3)	Imperf. Cred (4)
ρ_R	0.91	0.71	0.73	0.66
α_π	1.37	1.47	1.59	1.58
α_y	0.46	0.42	0.39	0.49
α_S	2.95	0.18	Calib	Calib
Log data density	2777.23	2770.27	2764.78	2736.23

We can compare the four specifications of the model through the log marginal density of the data (shown in the last row of table 8), computed through 500,000 Metropolis Hastings simulation (discarded the first 20 percent). The log data density allows us to compare the empirical fit of a model. It indicates how likely it is that the model had generated the data. In the Bayesian context, the ratio between the density data of two alternatives model states the relative posterior probability of these two specific models.

We observe that the specifications including a monetary policy response to the nominal exchange rate (specifications 1 and 2, reported also in tables 6 and 7) are identified as more likely to have generated the data. Between them, there is a better performance when we include the possibility of imperfect credibility. Taking the exponential of the difference of

[10]For the inferred probabilities and the conditional ERPT we use the mode of the estimated parameters.

the log data density of specification 1 and 2, we obtain a value $\exp(6.96) \approx 1052.32$, which means that the imperfect credibility model is about one thousand times more likely to have generated the data relative to the perfect credibility model. If, instead, we impose that the monetary policy does not respond to the exchange rate movements (specifications 3 and 4), the empirical fit worsens with respect to specifications 1 and 2. Moreover, the model with imperfect credibility and no exchange rate stabilization has lower log data density than the model with perfect credibility and no exchange rate stabilization.

We can therefore conclude that there are two crucial elements to consider when modelling the Uruguayan economy in terms of the dynamics of inflation, exchange rate and monetary policy. First, one needs to take into account that the central bank is concerned about avoiding fluctuations in the exchange rate when deciding the interest rate. Second, it is important to consider the imperfect anchoring of inflation expectations around the inflation target. Both ingredients need to be included jointly in order to have a good empirical fit. These estimations show clear evidence that, from the market's perspective, the central bank aims to stabilize the exchange rate when conducting its monetary policy and it has difficulties in keeping inflation expectations well anchored.

When analyzing the posteriors for the parameters in the monetary policy rule, we observe a huge increase in the estimated response to the exchange rate when we introduce imperfect credibility. Although the prior for this parameter has a mean of zero and it is the same under perfect and imperfect credibility, the data show that when we consider the possibility of imperfectly anchored inflation expectations, the central bank's concern for stabilizing the exchange rate is estimated as far more pronounced. Consequently, the two considerations mentioned above interact with each other. Including imperfect credibility in regards to anchoring medium term inflation expectation provides a clear identification of the exchange rate stabilization coefficient, which is less evident when we assume perfect credibility. The model suggests that the Central Bank of Uruguay would not be able to reduce the ERPT by only allowing the exchange rate to float more freely; it must also succeed in anchoring inflation expectations around the inflation target.

Since specification (1) has the best empirical fit to the data, we focus only in this specification for further analysis below.

Under the imperfect credibility version of the model (1) the relevant parameter to capture the degree of credibility in the Uruguayan economy is μ, which corresponds to the unconditional probability (across all shocks) of the belief that the central bank is keeping the inflation target constant. Hence, $1 - \mu$ is the unconditional probability assigned by private agents to the belief that the central bank is changing the inflation target in response to shocks.[11] If μ were equal to one, it would coincide with the case of perfect credibility. The estimated posterior mode for this parameter is 0.43, which means that there exists a credibility problem in monetary policy and it is quite significant.[12]

Using the Kalman filter from the model computed with the mode of the parameters we can obtain the estimated value $\omega_{j,t}$ based on the inference about $\hat{\varepsilon}_{j,t}$ and $\tilde{\varepsilon}_{j,t}$, using the transformation that $\omega_{j,t} = (\hat{\varepsilon}^2_{j,t})/(\hat{\varepsilon}^2_{j,t} + \tilde{\varepsilon}^2_{j,t})$. The estimated value for $\omega_{j,t}$ corresponds to the probability assigned by the private agents to a constant inflation target in response to shock j in period t. With that information, we can compute the average value for this probability over the whole sample. Figures 1 and 2 present the unconditional probability assigned to an invariant inflation target (μ), the average observed probability of this conditional in shock j (average of $\omega_{j,t}$), and the time varying of this probability ($\omega_{j,t}$).[13] Figure 3 shows the simple average of $\omega_{j,t}$ across all shocks presented in figures 1 and 2.

We find considerable variation over the sample period regarding credibility inferred by the model. The results also vary according to the shock considered. For instance, the foreign interest rate shock, foreign demand shock and non-core inflation shock would suggest a loss of credibility at the end of the sample, while the sovereign spread shock would point in the other direction.[14]

4.2 Quantification of the exchange rate pass-through

In order to analyze the relevant shocks to the exchange rate, table 9 reports the asymptotic variance decomposition of this variable and headline inflation -under imperfect credibility- for the six shocks with the highest explanatory power regarding the variance of the exchange rate. We can notice that six external shocks explain around 53% of the variance of the exchange rate: the foreign risk-free rate, sovereign spread, exchange rate risk, foreign inflation, non-core inflation and the shock to the price of imported goods with high exchange rate pass-through. Accordingly, we use these six external shocks to compute the ERPT.[15]

[11] Recall that μ is the unconditional value for $\omega_{j,t}$ across all shocks.

[12] If the upper bound of the target range is considered as the target inflation rate, then the estimation for μ is 0.7, which suggests that using the upper value of the inflation range estimates a less severe credibility problem.

[13] The time varying probabilities presented in figure 1 are the four quarters moving average.

[14] In the case of non-core inflation shocks, since the government could have used administered prices to control inflation (for example, by implementing the "UTE premia" plan in December 2012 and keeping a reduction in the price each year afterwards), we could interpret the results as an indication that this type of shocks can actually affect the private sector's perception of the monetary policy target. Nevertheless, this interpretation is tentative, but it might suggest other aspects beyond the central bank's actions that could have impacted the market belief regarding the medium term inflation target.

[15] The appendix contains the ERPT for the other seven shocks included in the model with imperfect credibility, which are shown in figures 10 to 16.

Table 9: Asymptotic Variance decomposition

Variable	R_t^{US}	ξ_t	ζ_t	π_t^*	$\psi_{F,t}$	$P_{NX,t}$	Other shocks
$Var(S_t/S_{t-1})$	3.0	4.6	19.6	11.7	3.6	4.9	52.5
$Var(\pi_t)$	2.9	4.5	10.6	11.3	19.6	8.6	42.5

For a given external shock j, the ERPT to inflation of type i is computed as:

$$ERPT_{t|j}(i) = \frac{\sum_{n=1}^{t} \pi_{n|j}(i)}{\sum_{n=1}^{t} \Delta S_{n|j}} \tag{31}$$

where $\pi_{n|j}(i)$ is the impulse response function of the quarterly inflation of type i in period n after shock j hits the economy in period 1, and $\Delta S_{n|j}$ is the impulse response function of the quarterly exchange rate devaluation in period n after the same shock j hits the economy in period 1. Therefore, $ERPT_{t|j}(i)$ measures the accumulated exchange rate pass-through in inflation type i up to period t in response to the shock j. Using the mode of the parameters we compute the ERPT to three different components of the CPI: headline inflation (π_t), home good inflation ($\pi_{H,t}$), and foreign good inflation ($\pi_{F,t}$). The ERPT is also obtained conditional on a belief that the inflation target is invariant ($\omega_{j,t} = 1$), which corresponds to a case where the private agents have perfect credibility on the fact that the central bank is keeping the inflation target constant, but the monetary policy rule is the estimated under imperfect credibility model. Alternatively, we can compute the ERPT conditional on the belief that the inflation target is changing ($\omega_{j,t} = 0$), that is a situation in which private agents believe that the inflation target varies in response to shock $\varepsilon_{j,t}$. It is worth noting that these two scenarios are hypothetical, while the Uruguayan case would correspond to an average between the two of them (as μ has an estimated posterior mode of 0.43). Figures 4 to 9 show these computations of the ERPT conditional both on each relevant external shock and on the belief of invariability in the inflation target ($\omega_{j,t} = 1$) or on the perception of regular changes in the inflation target ($\omega_{j,t} = 0$).

Figure 4 depicts the conditional ERPT for a foreign risk free interest rate shock. Under the market's belief of invariability in the inflation target, a positive change in the foreign risk free interest rate increases the incentives to save in the current period (intertemporal substitution effect) and a negative income effect, since Uruguay is a net debtor. Both effects imply a decrease in aggregate demand. This decline in demand and the increase in labor supply foster a reduction in the relative price of the home goods, which triggers a real depreciation. Since prices are sticky, the nominal exchange rate increases and so do the imported prices. Thus, the ERPT is negative for domestic inflation ($\pi_{H,t}$), and positive for the other inflation indicators. Under the market belief of a changing inflation target, the high ERPT observed for imported goods ($\pi_{F,t}$) remains almost the same. But private sector's expectations affect both the expected path of the monetary policy interest rate and inflation expectations, which translates into an increased ERPT for domestic good inflation.

Figure 5 shows the conditional ERPT of the sovereign spread shock. The transmission mechanisms for an increase in the sovereign spread shock are similar to those observed for a foreign interest rate shock. Therefore, when private agents believe that the monetary policy target remains constant no matter which shock hits the economy, the ERPT is negative for domestic inflation. The conclusion for the ERPT in response to sovereign risk shocks is also similar to what we see in figure 4. For foreign prices the ERPT is similar under belief of invariant or changing inflation target, while for domestic goods the sign of the ERPT changes. The price of domestic goods, which partially offsets the inflationary effects of the shock when there is a belief of invariant inflation target, adjust in an increasing manner in the case of the perception of a changing inflation target, which results in a general higher exchange rate pass-through.

An increase in the exchange rate risk shock results in a rise in the nominal exchange rate and imported inflation. The response of monetary policy, however, discourages the increase in domestic inflation. Figure 6 presents the ERPT for this shock. The results of incorporating imperfect credibility about invariability of the inflation target are qualitatively analogous to the cases previously analyzed; the exchange rate pass-through increases for domestic inflation, which reinforces the inflationary pressures stemming from the imported inflation.

Under the belief of a constant inflation target, an increase in foreign inflation imposes a downward pressure on the real exchange rate (appreciation). In order to restore equilibrium, and with nominal price rigidities, the nominal exchange rate decreases. In the case of Uruguay, this shock usually takes place when the trade partner's currencies are appreciating. Therefore, an increase in foreign inflation goes along with a gain in competitiveness, which translates into an increase in domestic good prices. The resulting ERPT is negative for domestic goods, but also for headline inflation (see figure 7). With a belief of a changing inflation target, this pass-through to domestic good prices is quite relevant, which results in a higher ERPT for headline inflation, but still in negative ground.

The result for a shock to the price of imported goods with high exchange rate pass-through and its conditional ERPT are depicted in Figure 8. This shock, as expected, translates into a significant ERPT to imported inflation with both type of belief of the variation or not of the inflation target.

Finally, the last shock considered is on the non-core prices (Figure 9). In the event of these shocks there is a tension between two of the central bank's objectives: stabilizing prices and the exchange rate volatility. As a result, the nominal interest rate falls and there is an appreciation of the real exchange rate.

In sum, we find significant differences among the conditional ERPTs, depending on the shock that is hitting the economy, on the CPI component considered and on the assumption on private sector's inflation expectations formation.

First, the dynamics that underlie the nominal exchange rate fluctuations are different for each shock. As a result, we obtain different degrees of ERPT according to the shock that triggers the exchange rate movement. In general, the ERPT tends to be lower for shocks that have a higher aggregate demand effect. The smallest ERPT occurs after a shock on foreign inflation, since in that case the ERPT on domestic good inflation is negative, even under the belief of a changing inflation target. This result is consistent with the existing literature on conditional ERPT such as García-Cicco and García-Schmidt (2020), Palleja (2018) and Güenaga and Zacheo (2019), who find that the conditional ERPT after a foreign inflation shock has a lower magnitude than that caused by disturbances to the relevant foreign interest rate.

Second, the ERPT to imported good prices is higher than to domestic good prices, since the latter tend to absorb part of the relative price adjustment required by the shocks. Since CPI is computed as an average of domestic and imported prices, its conditional ERPT lies between both conditional ERPTs. All in all, the ERPT for headline inflation is quite relevant (similar to other estimations for Uruguay[16]) when we allow for private belief of changing inflation target, reaching levels of more than 0.2 for the first four quarters after the shock hits the economy.

Finally, when private agents perceive that the inflation target may change after a shock hits the economy, i.e., under imperfect credibility, the conditional ERPT to headline inflation is higher for every shock considered when the market has less well anchored the medium term inflation expectation around its target.

5 Final remarks

In this work we have estimated a New-Keynesian model for the Uruguayan Economy featuring the possibility of imperfect credibility in the monetary policy. We have focused on analyzing quantitatively the exchange rate pass-through (ERPT) using the estimated

[16]The most recent studies for Uruguay have estimated unconditional coefficients of 0.12 for the period 2000-2015 (Carrière-Swallow et al. (2016)), 0.40 for 1989-2010 (Gianelli (2011)), while the last study (Güenaga and Zacheo (2019)) estimated conditional measures from 0.04 to 0.14 for the period 2005 to 2017, for the first quarter after the shock.

model. We have five main results.

First, the Bayesian approach used to estimate the model highlights that the version with imperfect credibility in the monetary policy has a posterior empirical fit about one thousand times better than the model with perfect credibility. Second, the estimated degree of imperfect credibility is quite relevant and it shows a significant variation across shocks and over time. Third, conditional on a specific shock, the ERPT is lower when the shock has a higher offsetting effect in aggregate demand. Fourth, the ERPT is also lower when the monetary policy is credible in keeping the inflation target constant.

Finally, we identify two interlinked aspects to characterize the monetary policy in Uruguay. On one hand, the estimation suggests a central bank's concern to stabilize the exchange rate with the short-term interest rate. On the other hand, the central bank faces a difficulty to anchor inflation expectations around its target. The empirical fit of the model favors the joint presence of these two aspects. The estimation also identifies a more pronounced exchange rate stabilization when we allow for imperfect credibility in anchoring inflation expectations in the medium term. Hence, improvements in the conduct of monetary policy in Uruguay require to take into account these two aspects together, not separately.

Our results have stressed the variation of the ERPT depending on the specific shock and the monetary policy credibility. However, the model could be modified to include other factors that have been discussed to describe the monetary framework in Uruguay. For instance, price dollarization of several imported goods for the final consumers is a usual practice in Uruguay (see Barón et al. (2017), Licandro and Mello (2019)). Our treatment of having a fraction of imported goods with complete ERPT is an effort in that direction, but other modelling choices connecting money and price dollarization could be relevant to explore. Likewise, the precise characterization and evolution of the monetary policy instruments in Uruguay, beyond the short-term interest rate, is something analyzed in other studies (e.g. Basal et al. (2016)). We leave these potential extensions for future research. Regarding the inflation target, we have used the mid-point of the range set by the monetary authority (5%). A robustness analysis using the upper part of that range (7%) as the implicit inflation target moderates the results of imperfect credibility, but it keeps the same conclusions obtained.[17]

[17] These alternative estimations are available upon request.

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Figure 1: Inferred probabilities of perfect credibility, part I

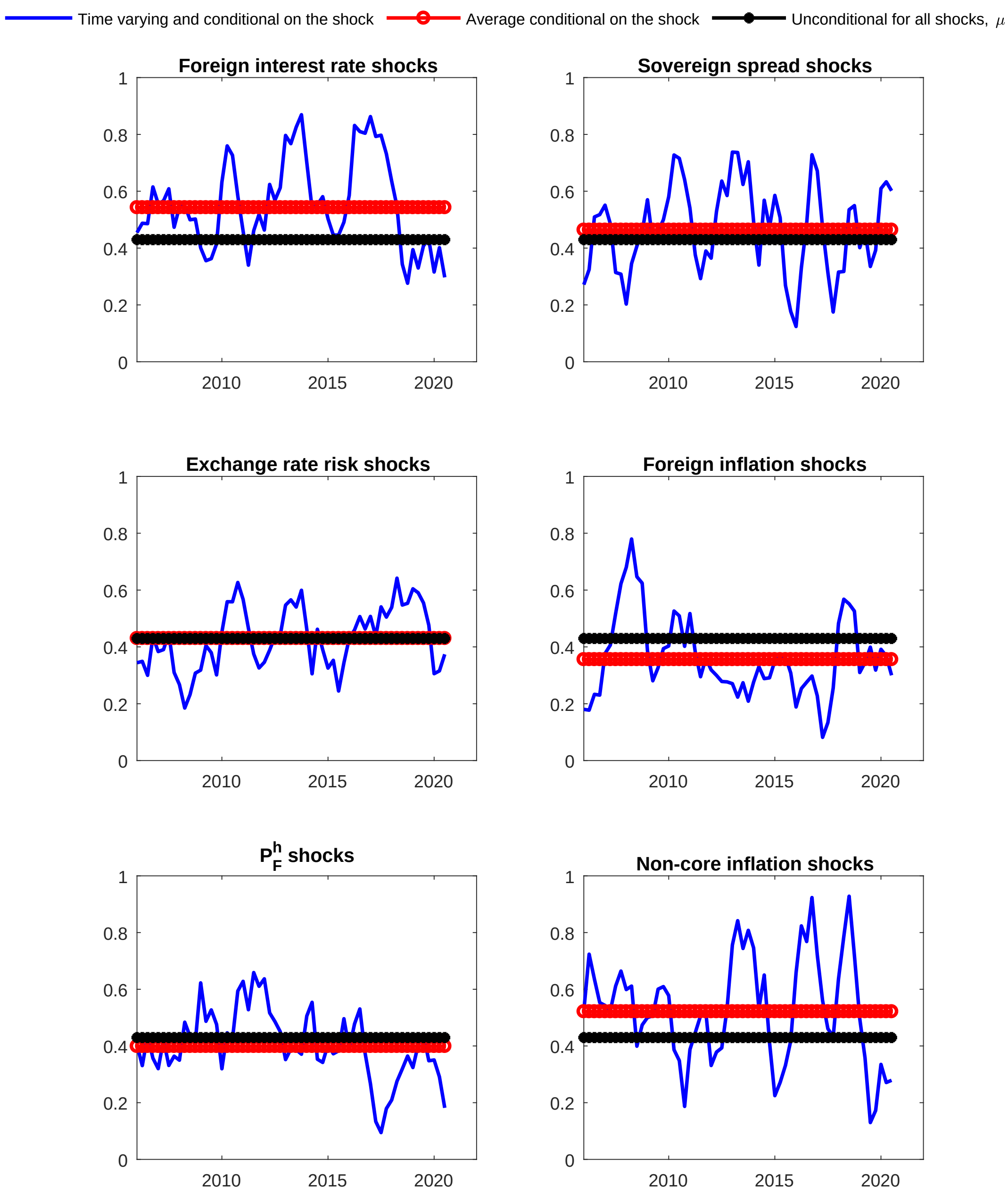


Figure 2: Inferred probabilities of perfect credibility, part II

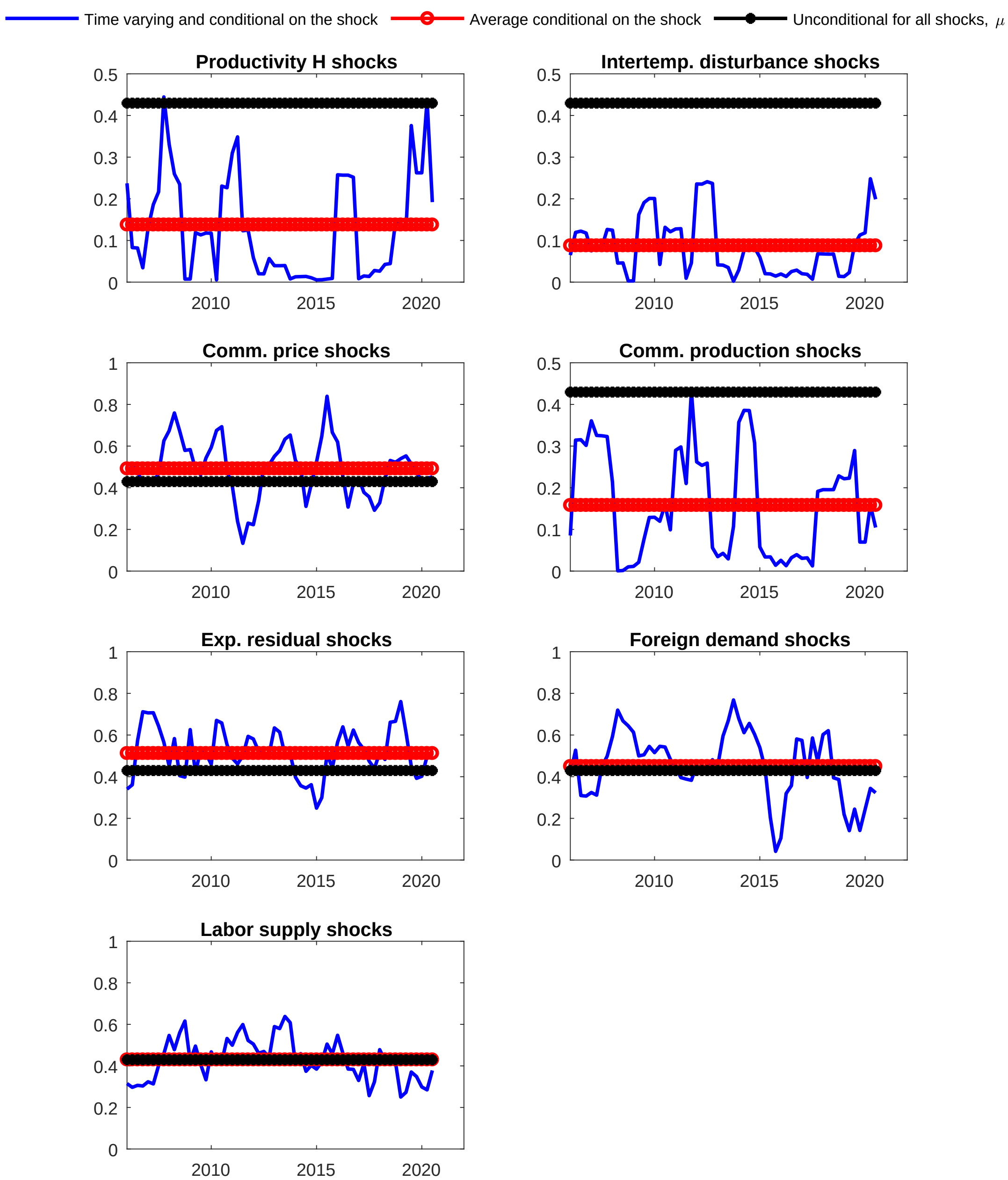


Figure 3: Inferred probabilities of perfect credibility. Average across shocks

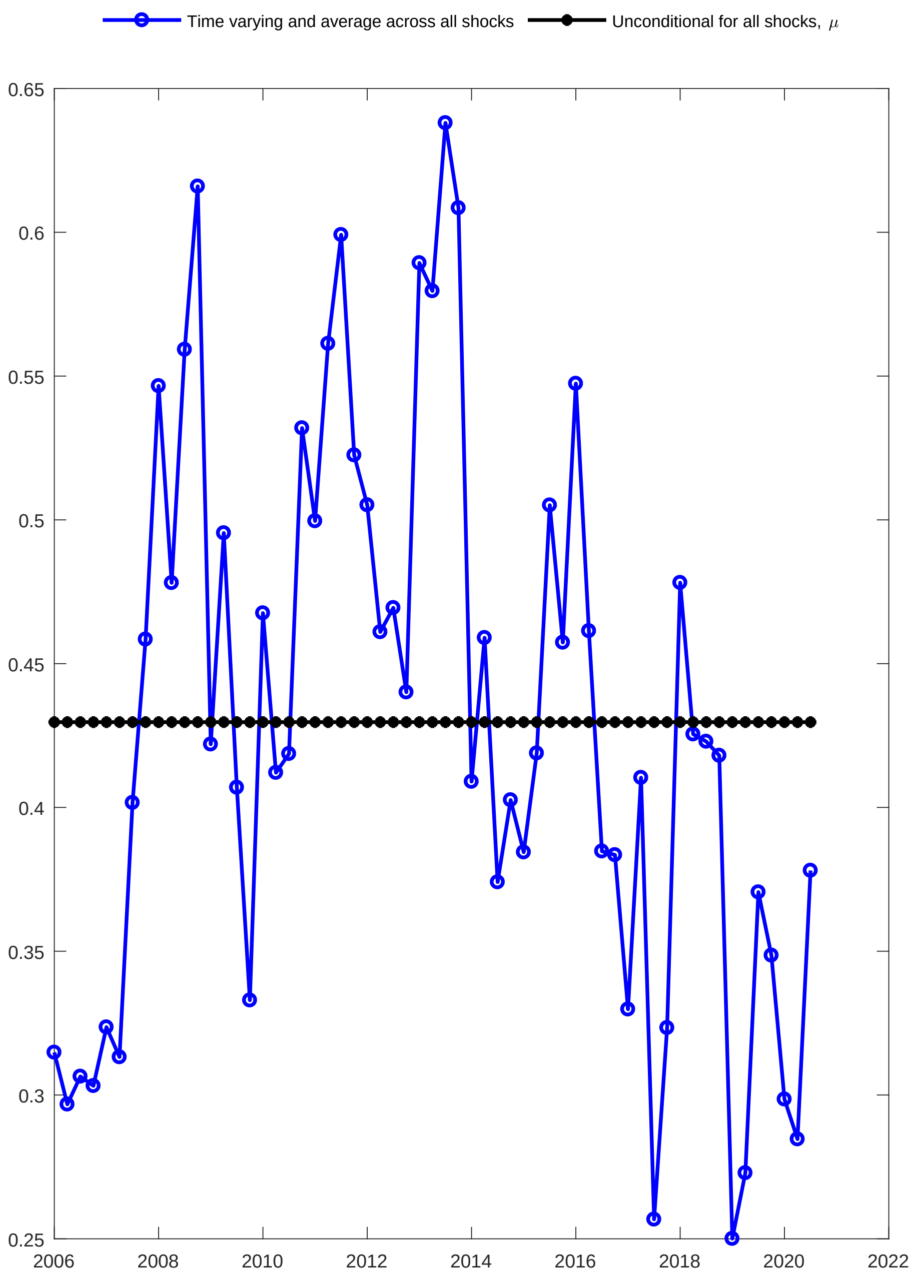


Figure 4: ERPT conditional on foreign risk-free rate shocks

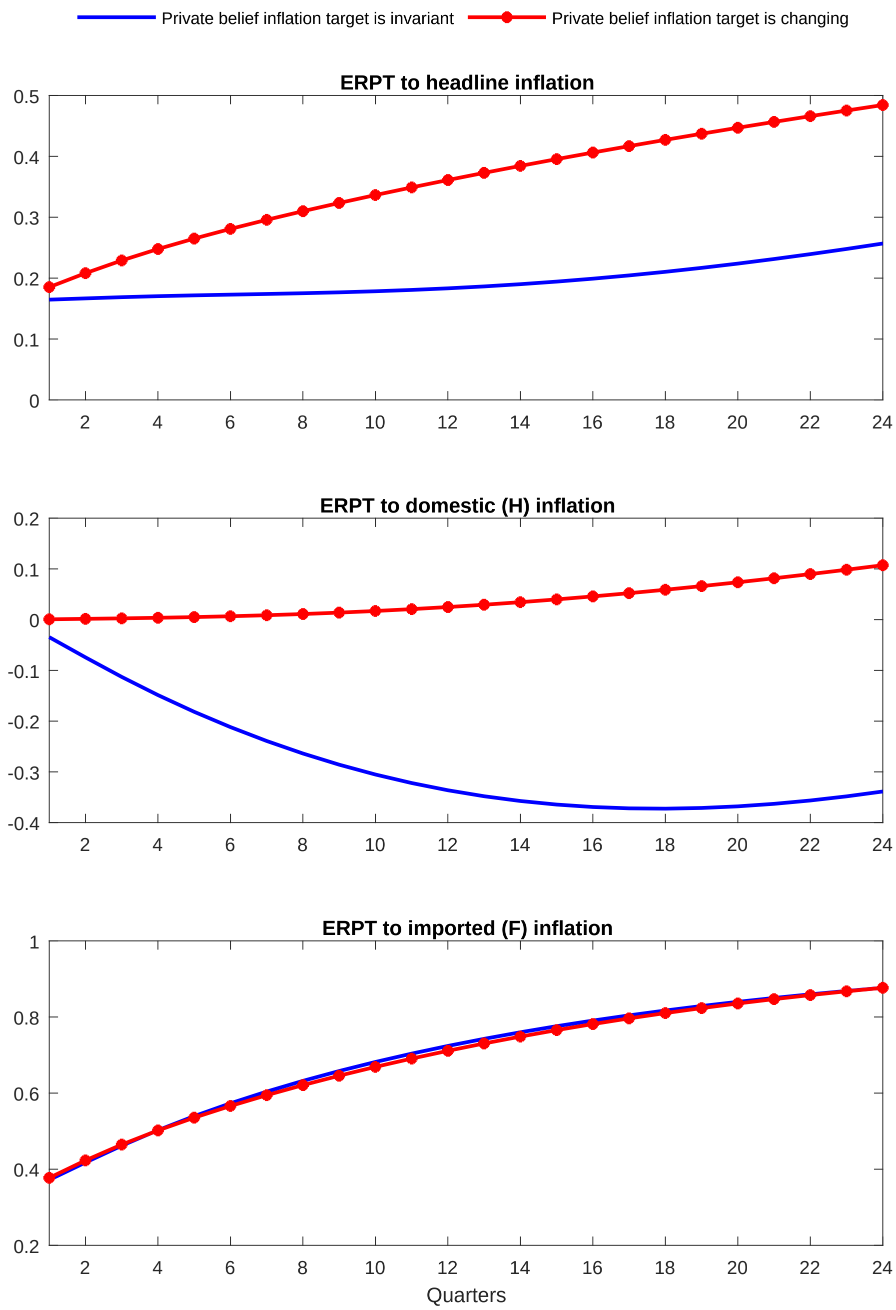


Figure 5: ERPT conditional on sovereign spread shocks

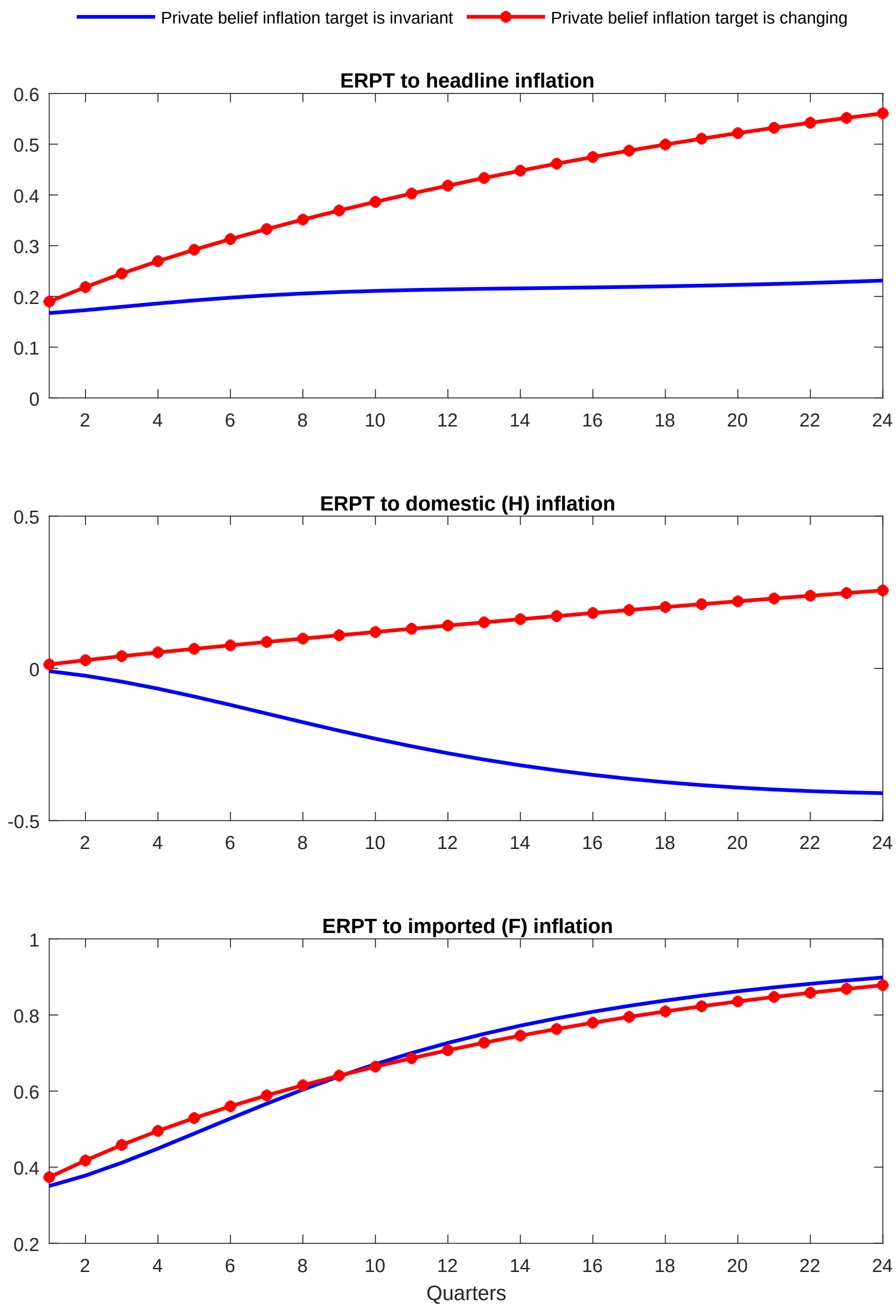


Figure 6: ERPT conditional on exchange rate risk shocks

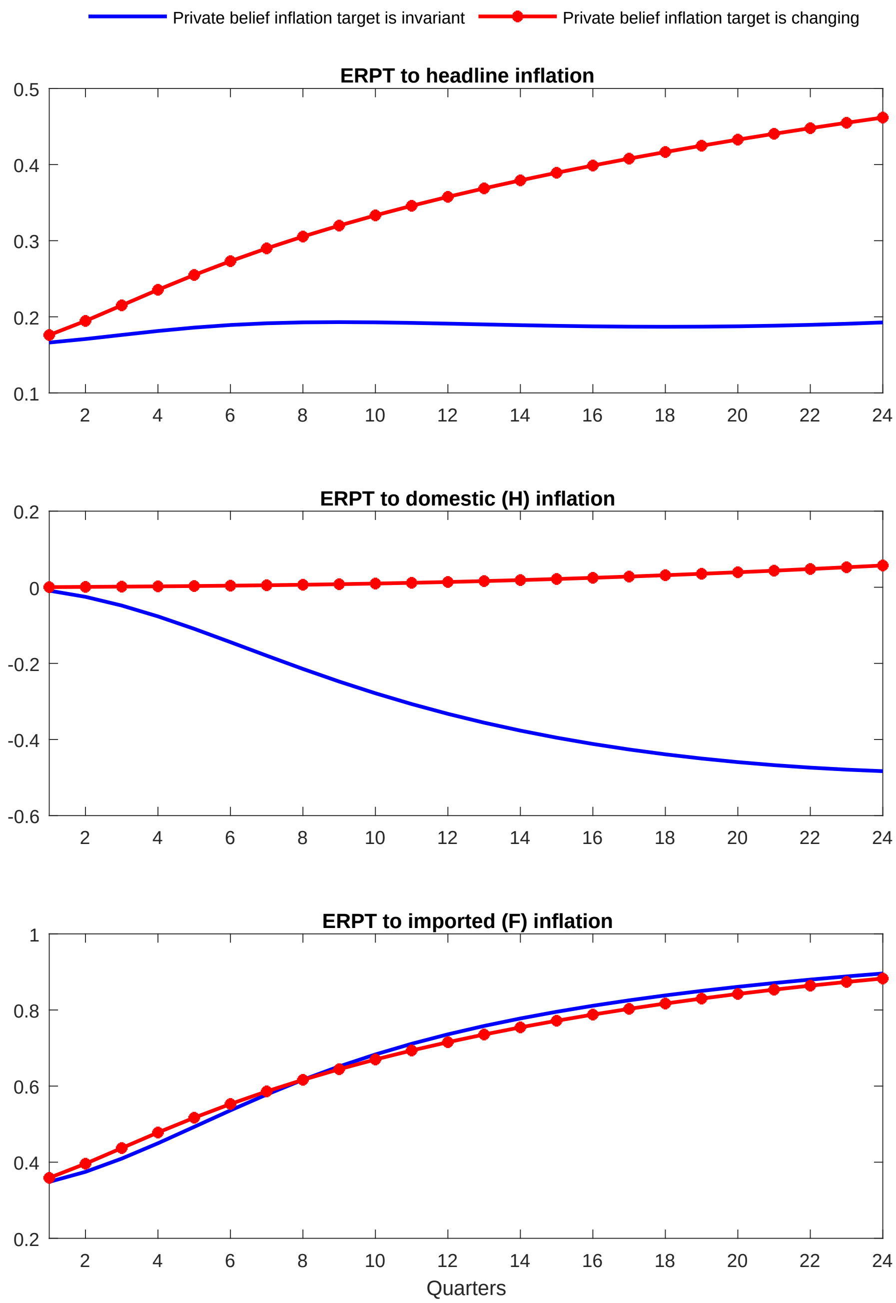


Figure 7: ERPT conditional on foreign inflation shocks

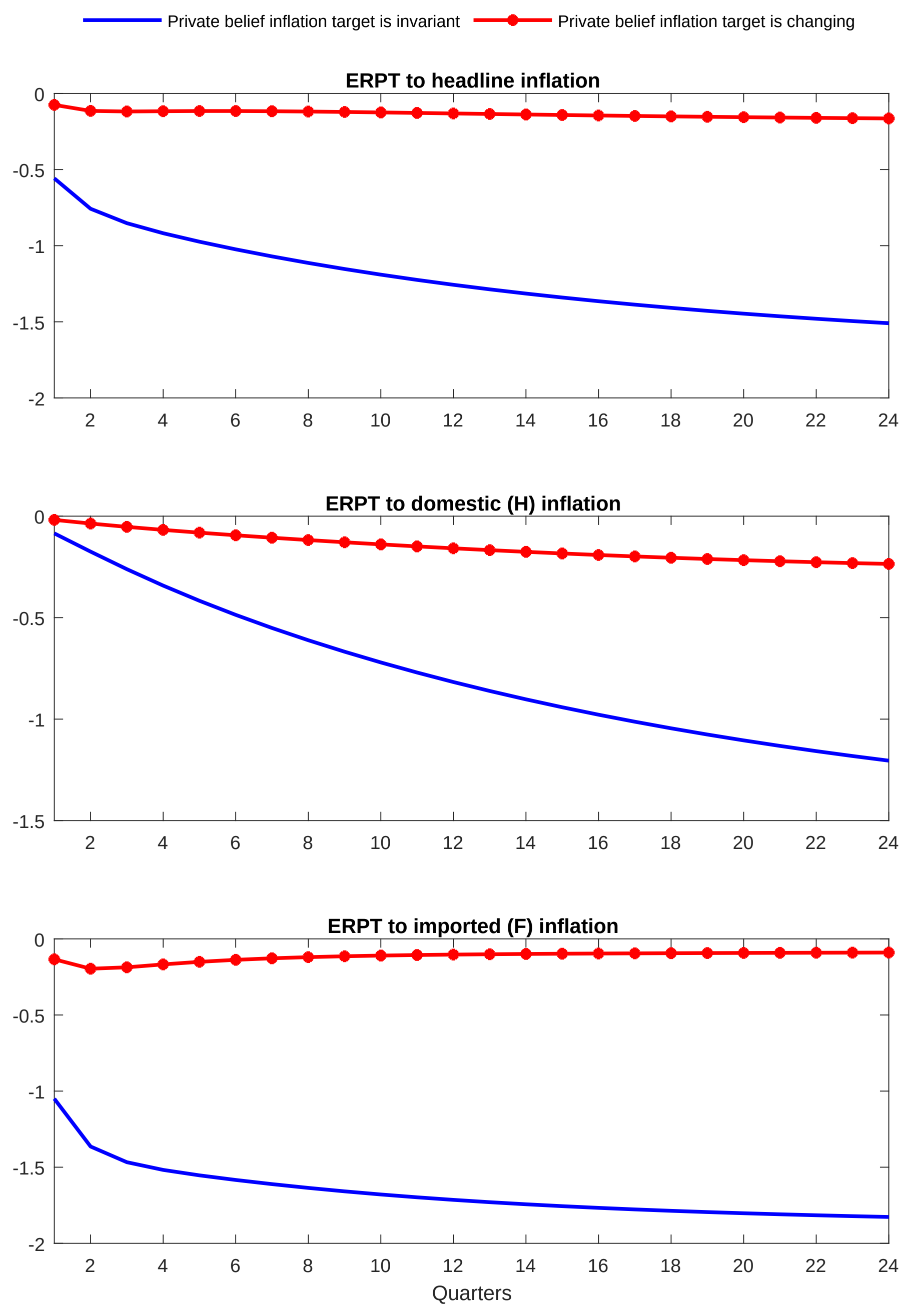


Figure 8: ERPT conditional on $\psi_{F,t}$ shocks

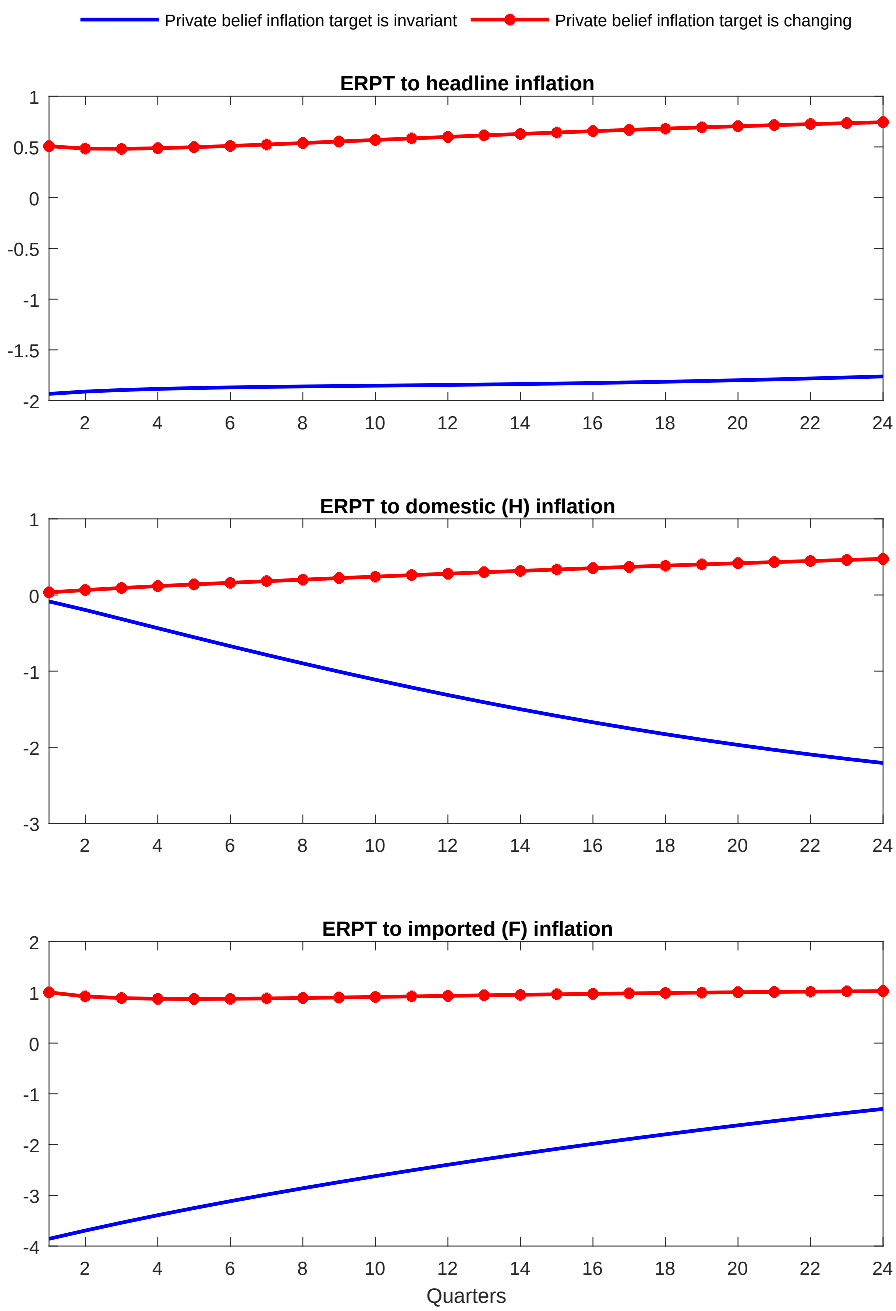
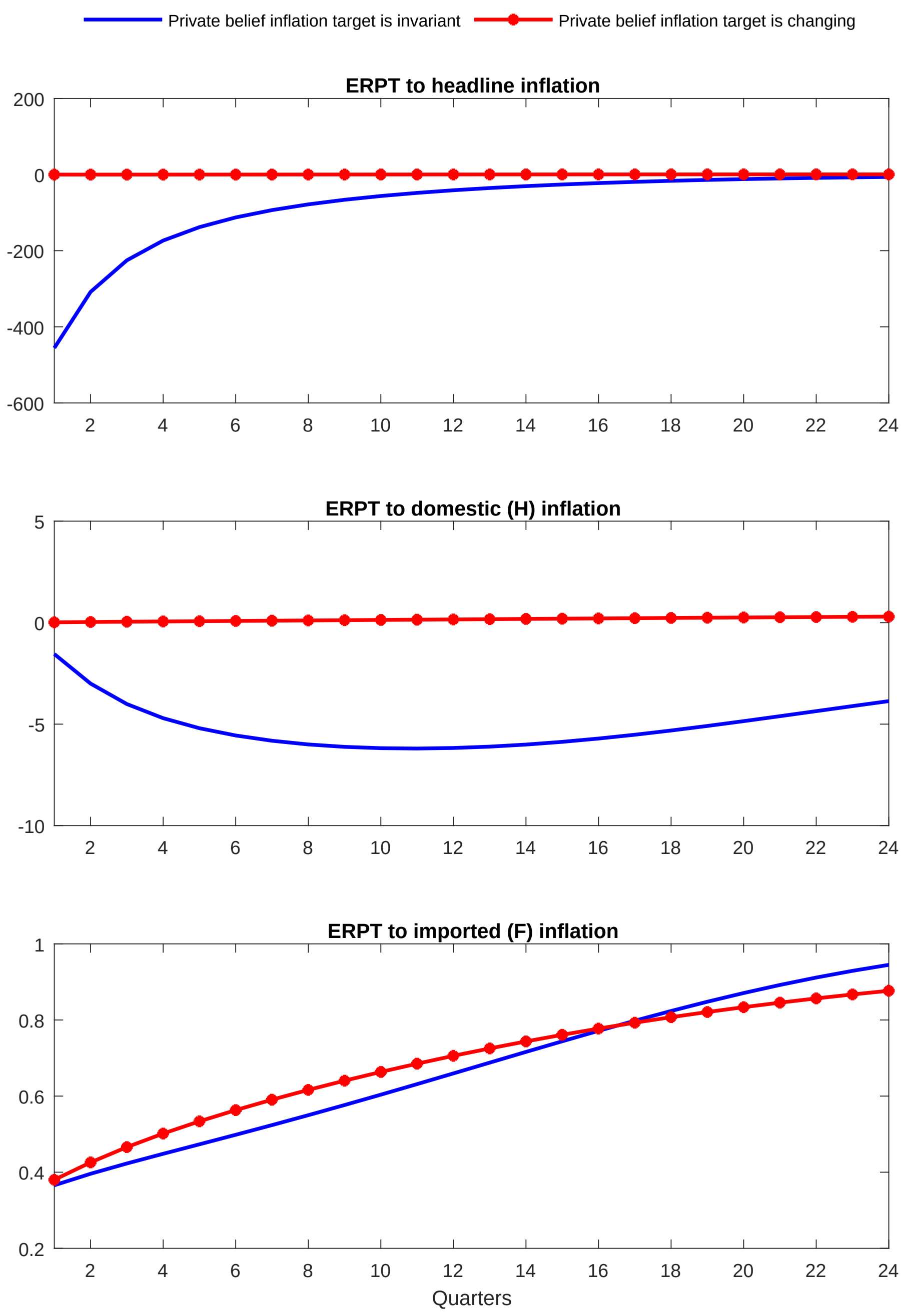


Figure 9: ERPT conditional on non-core price shocks



Appendix

Figure 10: ERPT conditional on productivity shocks in sector H

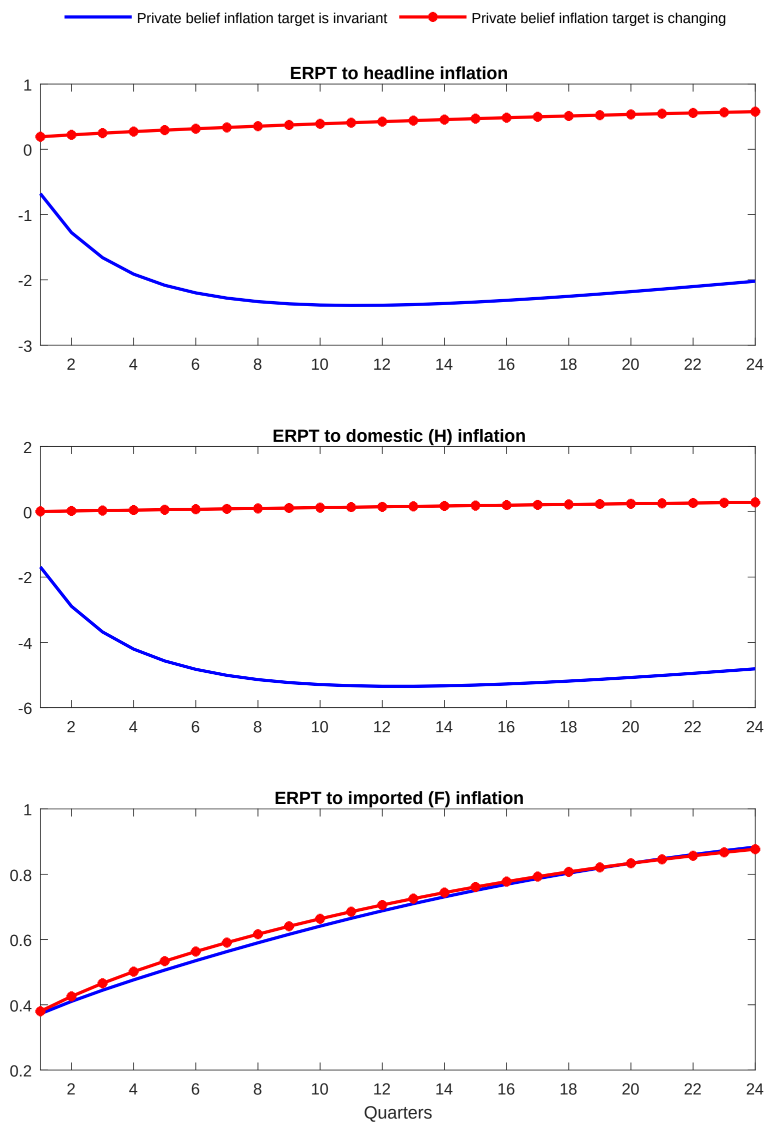


Figure 11: ERPT conditional on intertemporal disturbances

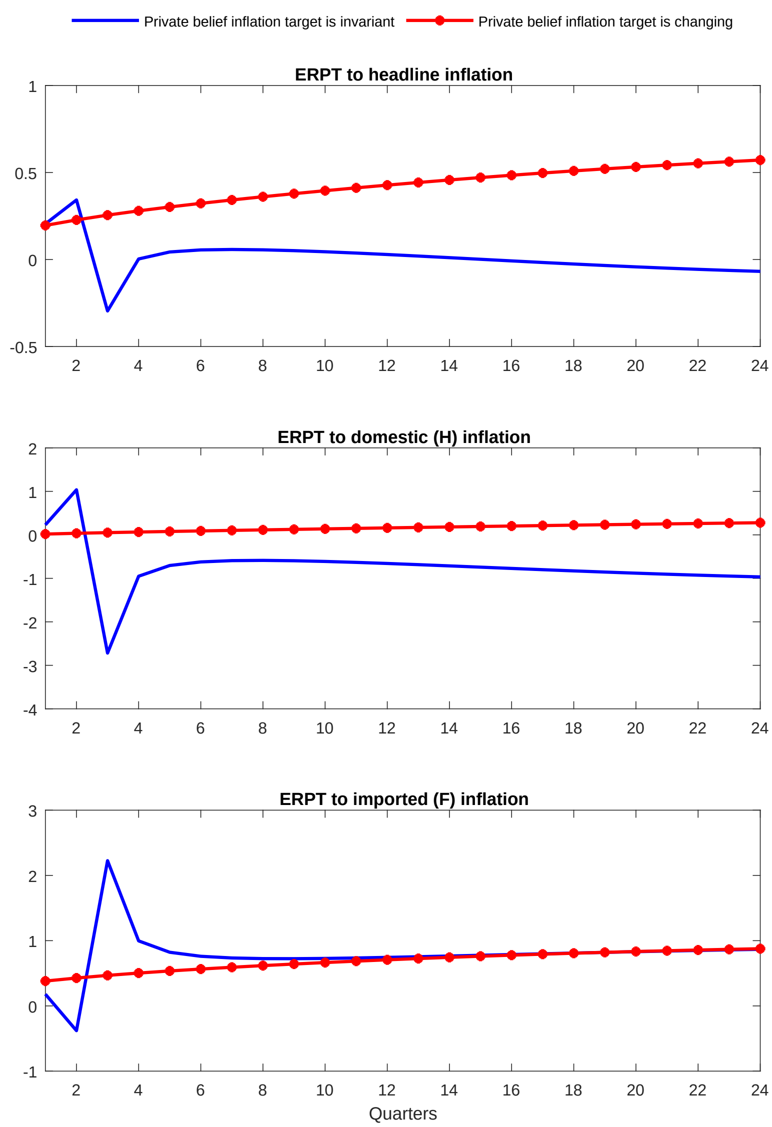


Figure 12: ERPT conditional on commodity price shocks

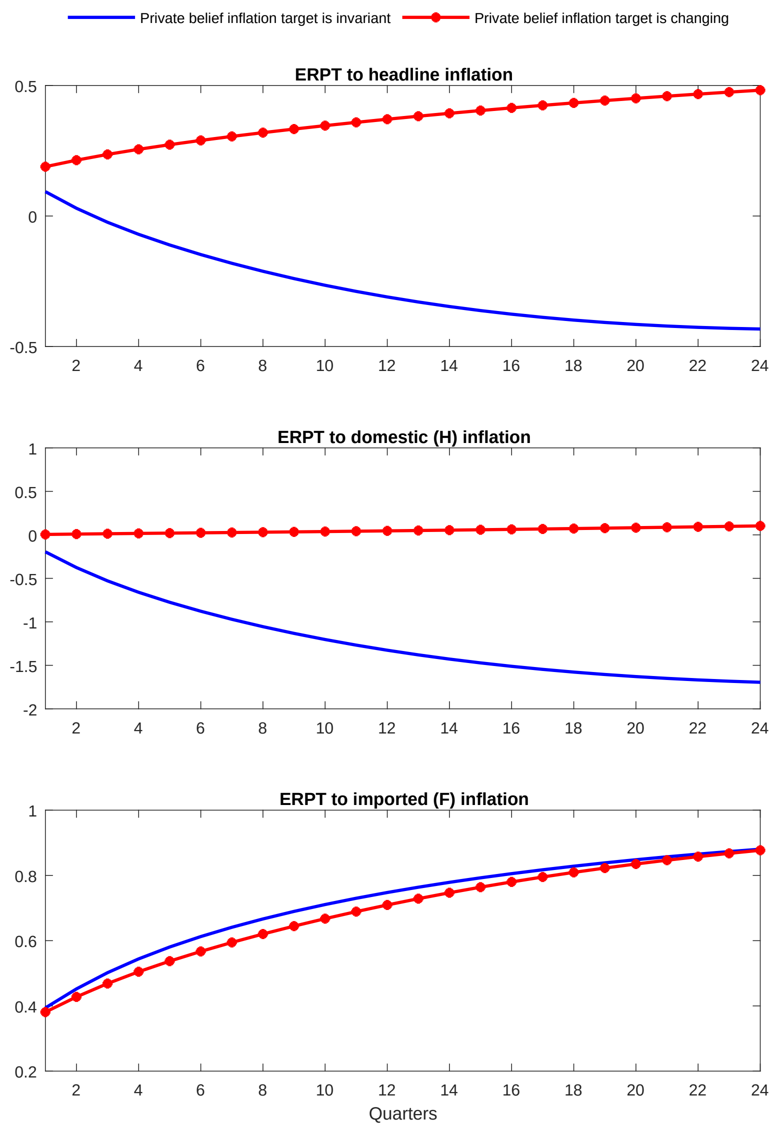


Figure 13: ERPT conditional on commodity production shocks

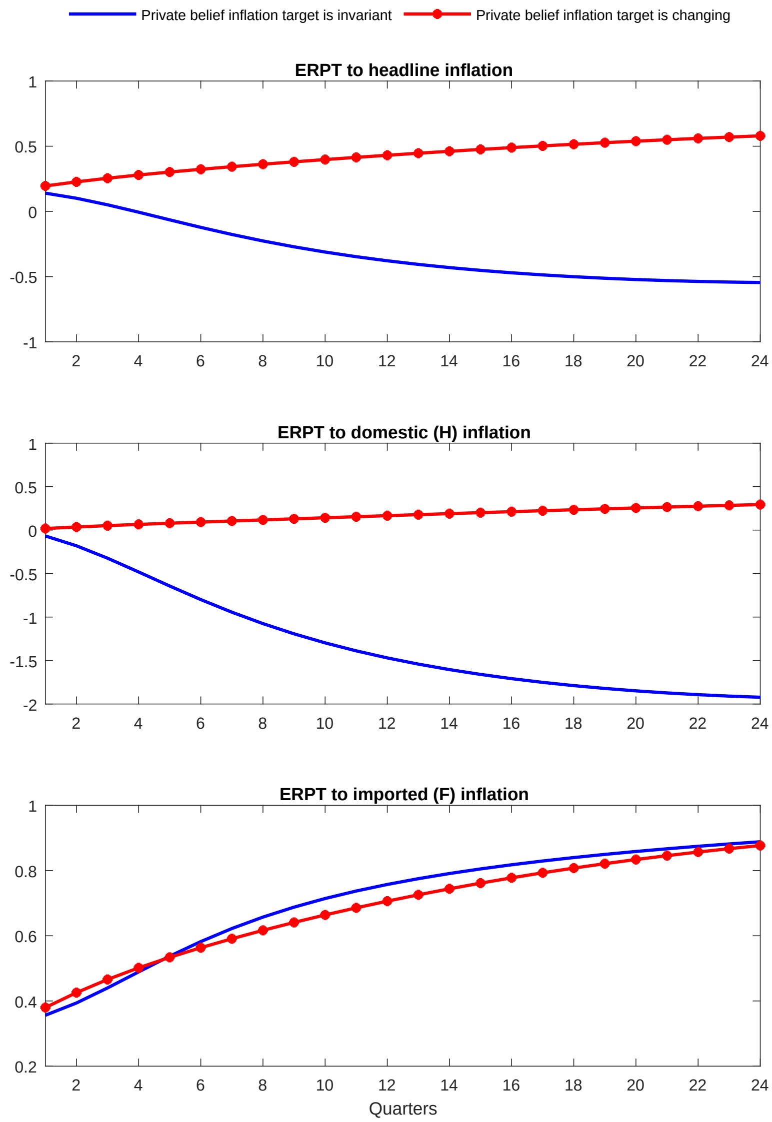


Figure 14: ERPT conditional on export residual shocks

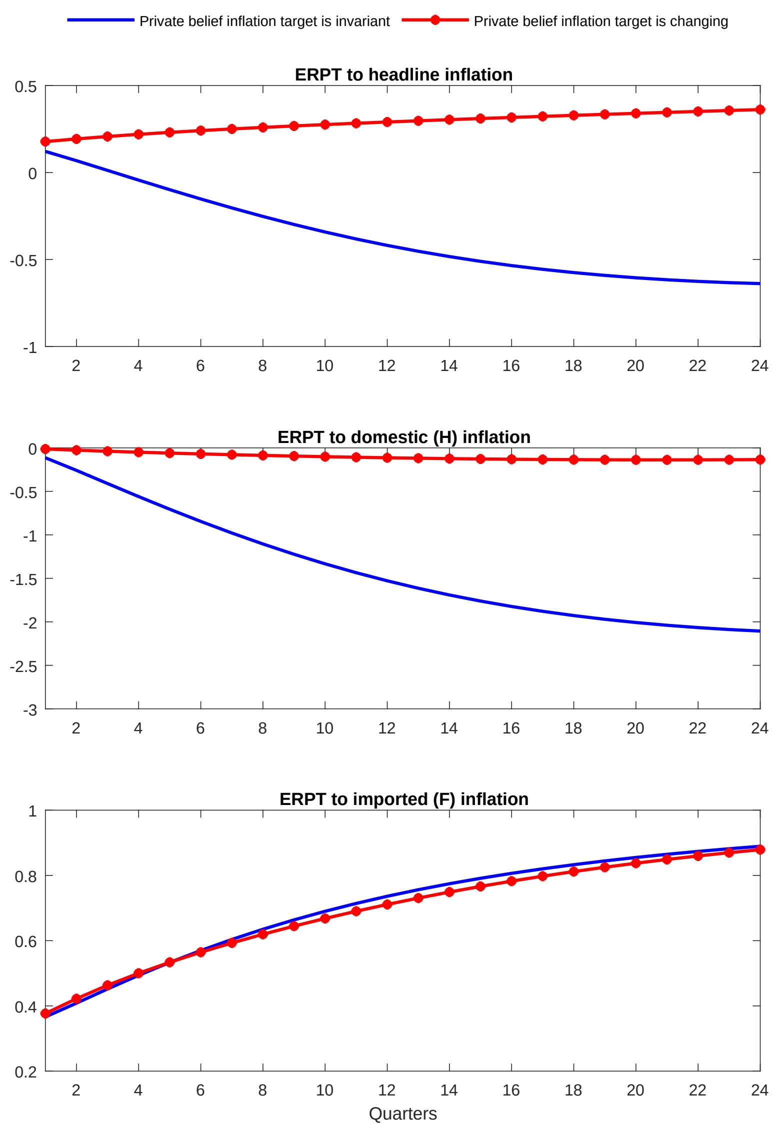


Figure 15: ERPT conditional on foreign demand shocks

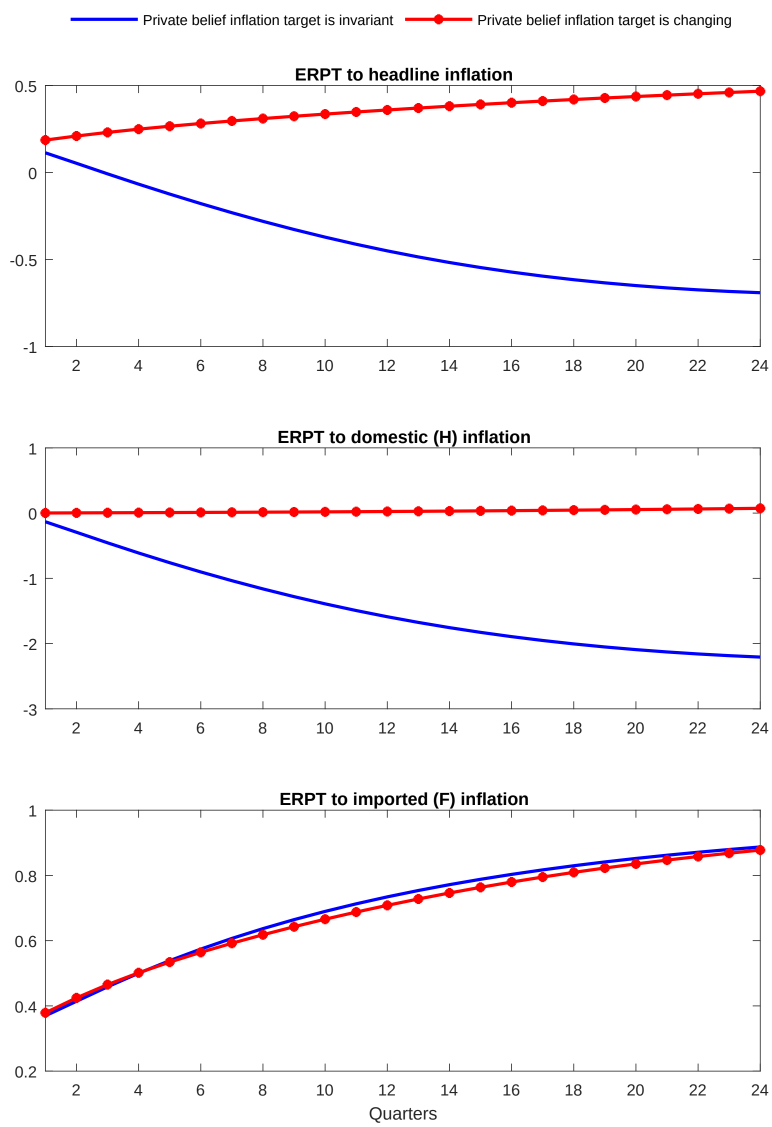


Figure 16: ERPT conditional on labor supply shocks