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Does the Central Bank of Peru Respond to Exchange Rate Movements? A Bayesian Estimation of a New Keynesian DSGE Model with FX Interventions*

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Abstract

This paper assess the role played by the exchange rate and FX intervention in setting monetary policy interest rates in Peru. We estimate a Taylor rule that includes inflation, output gap and the exchange rate using a New Keynesian DSGE model that follows closely Schmitt-Grohé and Uribe (2017). The model is extended to include an explicit sterilized FX intervention rule as in Faltermeier et al. (2017). The main empirical results show, for the pre Inflation Targeting (IT) and IT periods, that the model that clearly outperforms in terms of marginal log density, features a Taylor rule that does not respond to changes in the nominal exchange rate and an active use of FX intervention by the Central Bank. We also find that the coefficient associated with the response of the Taylor rule to inflation is close to 2 and the one associated with the output gap is greater than 1; and that FX intervention has become more responsive to exchange rate fluctuations during the IT period. Finally, the estimated IRFs shows that FX intervention has contributed to reduce the volatility of GDP in response to productivity and terms of trade shocks in Peru.

JEL Classification: C22, C52, F41.

Keywords: Small Open Economy; Taylor Rule; Monetary Policy Rule; Exchange Rate; Bayesian Methodology; Peruvian Economy; FX interventions; New Keynesian DSGE Model.

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¿Responde la Política Monetaria del Banco Central de Reserva del Perú al Tipo de Cambio? Una Estimación Bayesiana de un Modelo DSGE Neo Keynesiano con Intervención Cambiaria*

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Resumen

Este documento evalúa el rol que juega el tipo de cambio y la intervención cambiaria en la fijación de la tasa de interés de política monetaria en Perú. Estimamos una regla de Taylor que incluye la inflación, la brecha del producto y el tipo de cambio utilizando un modelo DSGE Neo Keynesiano basado en Schmitt-Grohé y Uribe (2017). El modelo se extiende para incluir una regla explícita de intervención cambiaria esterilizada como en Faltermeier et al. (2017). Los principales resultados empíricos muestran que tanto para el periodo anterior al regimen de metas explícitas de inflación (IT) como para el periodo del IT, el modelo que claramente muestra un mejor ajuste de los datos, medido por el logartimo de la función de densidad marginal, es aquél que presenta una regla de Taylor que no responde a cambios en el tipo de cambio nominal y en el que el banco central hace un uso activo de la intervención cambiaria. Asimismo, encontramos que el coeficiente asociado a la respuesta de la regla de Taylor a la inflación es cercano a 2 y el asociado a la brecha del producto es mayor que 1; y que la intervención cambiaria se ha vuelto más sensible a las fluctuaciones del tipo de cambio durante el período de IT. Finalmente, las funciones impulso respuesta (FIR) estimadas muestran que la intervención cambiaria ha contribuido a reducir la volatilidad del PBI frente a choques de productividad y de términos de intercambio en Perú.

Clasificación JEL: C22, C52, F41.
Palabras Claves: Economía Pequeña Abierta; Regla de Taylor; Regla de Política Monetaria; Tipo de Cambio; Metodología Bayesiana; Economía Peruana; Intervenciones Cambiarias; Modelo DSGE Neo Keynesiano.

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1 Introduction

The monetary policy rule proposed by Taylor (1993), has proven to be an accurate description of how Central Banks implement their monetary policy, particularly in developed economies, see Orphanides (2003). In closed economies, this rule states that interest rate can be characterized by a simple linear function that links interest rates to inflation and unemployment or output gap. For developed economies, Svensson (1997, 1999), Clarida et al. (1998, 2000), Judd and Rudebusch (1998), and Nelson (2001), provide empirical evidence supporting the role of inflation and inflation expectations, whereas, Favero and Rovelli (1999, 2003), Rodríguez (2008a, 2008b), emphasize the relevance of variables such as inflation, output gap and employment in the setting of monetary policy interest rates.

In open economies, the exchange rate plays an important role in setting interest rates. De Paoli (2009) shows that optimal monetary policy in small open economies that features home bias and incomplete financial markets includes exchange rate smoothing. Consistent with this result, Taylor (1993, 2001) and Ball (1999) find that including the exchange rate in the monetary policy rule may improve its performance in stabilizing long run inflation. Similarly, Leitemo and Södeström (2005) find that the inclusion of the exchange rate in the monetary policy rule reduces the volatility of imported inflation, outperforming a standard Taylor rule. In addition, Lubik and Schofheide (2007) -based in Galí and Monacelli (2005)- estimate Taylor rules using a DSGE model of a small open economy that show that monetary policy interest rates of Australia and New Zealand do not respond to exchange rate movements while the monetary policy of Canada and the United Kingdom do respond to exchange rates movements.

In emerging market economies, the role of exchange rates in setting monetary policy rates is more complex. On one hand, emerging economies have less developed financial markets which could contribute to amplify the impact of external shocks on domestic credit conditions; see Batini et al. (2010) and Gopinath (2015). On the other hand, many emerging markets, such as Peru, present financial dollarization which makes currency mismatches more frequent. Currency mismatches can amplify the impact of external shocks on the domestic financial system that, as Rossini et al. (2013) point out, increase the vulnerability of the economy to credit booms and busts associated with capital flows and the exposure of financial stability to exchange rate fluctuations. This could trigger negative balance-sheet effects, which may seriously affect the financial system and the real side of the economy see, Humala and Rodríguez (2010), Filardo et al. (2011), Morón and Winkelried (2005) and Carranza et al. (2003).

In response, some emerging countries use the interest rate to smooth exchange rate fluctuations. This behavior is known in the literature as "fear of floating", see Calvo and Reinhart (2002). Consistent with this narrative, Mohanty and Klau (2005) document that the response of the interest rate to changes in the exchange rate is even stronger than to changes in the inflation rate and the output gap in some small open economies. Instead, other Central Banks in emerging markets tend to rely on a larger number of monetary policy instruments as the use of international reserves and FX intervention, see Filardo et al. (2011). Likewise, Ostry et al. (2010, 2011), Gopinath (2019), Benes et al. (2015) and Adler and Tovar (2011), document that many emerging markets have been able to implement a counter-cyclical monetary policy during the global financial crisis by using a mixture of conventional and non-conventional monetary policy instruments.

Additionally, there is evidence that the FX intervention and the interest rate setting are related. For example, Ghosh et al. (2016), Ostry et al. (2011), Benes et al. (2015) and Canzoneri and Cumby (2014) point out that in the case of a capital flow shock, FX interventions reduce the need of adjusting the domestic interest rate to limit a large depreciation of the domestic currency, thus, preserving financial stability by limiting damaging negative balance-sheet effects associated with currency mismatches. Also, according to Céspedes et al. (2017), FX interventions could contribute to isolate domestic credit markets from the volatility and fluctuations of international financial markets by signaling that the exchange rate will remain at levels consistent to a "good equilibrium". Therefore, it is important to understand to what extent exchange rate fluctuations affect the monetary policy interest rate setting and how FX intervention can be used to isolate interest rate determination from exchange rate fluctuations.

This paper tackles these issues using as a case study Peru, a small open economy with dollarization. Our main objective is to assess the role played by the exchange rate and FX interventions in the setting of the interest rate. We do so by estimating a Taylor rule that includes inflation, output gap and exchange rate movements using a New Keynesian DSGE model that follows closely Schmitt-Grohé and Uribe (2017). We test simultaneously whether a model with a Taylor rule that includes exchange rate fluctuations outperforms a model with a Taylor rule that excludes exchange rate movements, similarly to the work of Lubik and Schorfheide (2007)[1]. To enrich the evaluation method of Lubik and Schorfheide (2007), we extended the model to include sterilized FX intervention under two alternative specifications: one in which the Central Bank follows a explicit rule of FX intervention that lean against external financial conditions as in Faltermeier et al. (2017), and a second specification where FX intervention is modelled as a deviation from the uncovered interest rate parity following Benes et al. (2015).

Peru, a small open commodity exporting economy with partial dollarization, offers a relevant case study to evaluate the role of FX intervention and exchange rate in the setting of interest rate. Since 2002, the Peruvian Central Bank follows an inflation-targeting (IT) regime that uses the short-term interest rate as its main instrument. Additionally, the Central Bank of Peru (BCRP henceforth) complement the use of interest rates with FX interventions, reserve requirements and international reserves accumulation to reduces the risks stemming from financial dollarization. In the last 20 years, the monetary policy authority has managed to keep the inflation low and stable. In fact, from 2007Q1 to 2008Q2 –before the financial crisis–, during the commodity price boom, the BCRP accumulated the equivalent to 18.5% of GDP of international reserves whereas during the financial crisis (2008Q3-2009Q1), the Central Bank used international reserves for an equivalent of 8.4% of GDP to mitigate exchange rate volatility and to preserve financial stability.

We estimate four different versions of the baseline model to assess the role of FX intervention in setting of monetary policy. The models differ in the restrictions imposed to the Taylor rule and FX intervention specifications. Model 1 is the less restrictive one, which considers a Taylor rule that responds to GDP growth, inflation rate and changes in the exchange

[1] See Del Negro and Schorfheide (2004) for previous works.

rate and considers an active FX intervention rule. The Model 2 contemplates the exchange rate in the Taylor rule and impose the restriction that the Central Bank does not intervene in indirectly in the FX market. The Model 3, imposes the restriction that the Taylor rule does not respond to changes in the exchange rate, but the Central Bank intervenes indirectly in the FX market. Finally, the Model 4 considers a Taylor rule that responds to exchange rate movements and a Central Bank that does not intervene in the FX market. The estimation employs quarterly time series for the period 1997Q1-2017Q4. All models are estimated using two samples. The first one that correspond to the pre-IT period (1997-2003) and the second, that coincide with the period where the IT regime period (2004-2017) has been in place. We rank the different estimations using the log density ratio.

The main empirical results show that the model that clearly outperforms all models in terms of marginal log density for the pre-IT and IT periods is the model in which the monetary policy rate does not respond to changes in the nominal exchange rate, and in which the BCRP actively intervenes in the FX market. This result is consistent with the IT plus control risk policy framework of the BCRP. In both samples, we find that the coefficient associated with the response of the interest rate to inflation in the Taylor rule is close to 2, consistent to the Taylor principle that guarantees that inflation is anchored. This result is also consistent with the low average inflation observed in Peru for the sample period. In addition, we find that the coefficient associated of GDP growth in the Taylor rule is greater than 1, which is in line with a counter-cyclical response of monetary policy, particularly in case of aggregate demand shocks. Also, we find that the response of FX intervention to fluctuations in the exchange rate has become stronger during the IT period, a feature that has contributed to reduce the volatility of GDP during this period. Finally, the estimation results also show that FX intervention, characterized by a larger response of FX to exchange rate reduces the volatility of GDP in response to productivity and terms of trade shocks, and that the forecast error variance decomposition shows that productivity and terms of trade shocks are the main source of uncertainty of the Peruvian economy. All our results are robust to the way FX intervention is modelled and to alternative priors of the estimated parameters.

The remainder of the paper is organized as follows. Section 2 presents and explains the DSGE model used in the estimation. Section 3 analyzes the main results and the robustness analysis. Section 4 concludes and the Appendix shows the equations of the model.

2 The Model

The model is based on Schmitt-Grohé and Uribe (2017). It is a model of a small open economy composed by households, two productive export sectors (commodities and manufacturing), a monetary policy authority and a foreign sector. Additionally, the model includes nominal rigidities a la Calvo on the final consumption goods prices. The Central Bank sets its monetary policy using a Taylor rule that responds to inflation, output and changes in the exchange rate. In addition, the Central Bank uses sterilized FX intervention to reduce the volatility of the exchange rate as in Faltermeier et al. (2017). The model captures two key features of the Peruvian economy: the large commodity exporting sector, mainly of minerals, which represent around 10% of its GDP and the frequent intervention of the Central Bank in the FX market, a distinctive feature of its monetary policy. The model considers households that consume final goods, supply labor, own commodity exporting firms, manufacturing firms and final goods firms and save using domestic and foreign assets. The model also considers firms that produce commodities, manufactured and final goods, using labor, capital and imported intermediate goods.

2.1 Households

Households demand final goods produced by the manufacturing sector and supply their labor hours (h_t) to the manufacturing firms for a salary (w_t). Also, households decide how much to consume (c_t), save in local currency (d_t) and in foreign currency (d_t^f). They maximize their utility function:

$$U_t\left(c_t, h_t\right) = \frac{\left[c_t - \left(\frac{h_t}{\omega}\right)^{\omega}\right]^{1-\sigma}}{1-\sigma}, \tag{1}$$

where ω is the inverse of the labor supply elasticity and σ is the inverse of the intertemporal substitution of consumption elasticity. The restriction of households is given by:

$$\begin{gathered} w_t h_t + \Gamma_t^x + \Gamma_t + s_t p_t^m d_{t-1}^f \left(1 + r_{t-1}^f\right) + d_{t-1}\left(1 + r_{t-1}\right) + u_t^x k_{t-1}^x + u_t k_{t-1} = \\ p_t c_t + p_t\left(k_t^x - (1-\delta) k_{t-1}^x\right) + p_t \Phi_{x,t}\left(k_t^x - k_{t-1}^x\right) \\ + p_t\left(k_t - (1-\delta) k_{t-1}\right) + p_t \Phi_t\left(k_t - k_{t-1}\right) - s_t p_t^m d_t^f - d_t, \end{gathered} \tag{2}$$

where s_t is the nominal exchange rate, p_t^m is the price of imported goods, p_t is the price of the final goods, r_{t-1} is the interest rate in $t-1$ in local currency, r_{t-1}^f is the interest rate faced by domestic agents in foreign currency, Γ_t^x are profits from commodity exporting firms, Γ_t are profits from domestic manufacturing firms, u_t^x is the cost of capital that commodities export firms pay to households and u_t is the cost of capital the manufacturing firms pay to households.

The capital of the commodities export sector is k_t^x with the following law of movement:

$$k_t^x = (1-\delta) k_{t-1}^x + \delta i_t^x, \tag{3}$$

where δ is the depreciation rate and i_t^x is the investment in the commodities export sector. The law of movement of the capital of the manufacturing sector k_t is

$$k_t = (1-\delta) k_{t-1} + \delta i_t^m, \tag{4}$$

where i_t^m is the investment in the manufacturing export sector. Furthermore, $\Phi_{x,t} = \frac{\varphi}{2}(k_t^x - k_{t-1}^x)^2$ is the capital adjustment cost of the commodities export sector and $\Phi_t = \frac{\varphi}{2}(k_t - k_{t-1})^2$ is the capital adjustment cost of the manufacturing sector, where φ captures the intensity of the adjustment costs.

Solving the problem of households, the Lagrange multiplier is defined by

$$\lambda_t = \left[c_t - \left(\frac{h_t}{\omega}\right)^{\omega}\right]^{-\sigma}, \tag{5}$$

and the labor supply of households is given by

$$h_t^{\omega-1} = \frac{w_t}{p_t}. \tag{6}$$

The Euler equations in local currency and in foreign currency, respectively, are:

$$\lambda_t = \beta E_t \left[\lambda_{t+1} \left(\frac{p_t}{p_{t+1}} \right) (1 + r_t) \right], \tag{7}$$

$$\lambda_t s_t = \beta E_t \left[\lambda_{t+1} s_{t+1} \left(\frac{p_t}{p_{t+1}} \right) \left(1 + r_t^f \right) \right], \tag{8}$$

where β is the discount factor.

2.2 Commodities Export Firms

The firms of this sector are price-takers as commodity prices are determined in international markets. Therefore, domestic commodities exporting firms take these prices (p_t^x) as exogenous. This sector only uses capital to produce y_t^x:

$$y_t^x = A_t^x \left(k_{t-1}^x \right)^{\alpha_x}, \tag{9}$$

where α_x is the parameter associated with capital in the production function and A_t^x is the productivity of the commodities exporters defined by an AR(1) equation:

$$\ln \frac{A_t^x}{A^x} = \rho_{A^x} \ln \frac{A_{t-1}^x}{A^x} + \epsilon_t^{A^x}, \tag{10}$$

where ρ_{A^x} is the persistence of the productivity in the commodity export sector, A^x is the steady state of the productivity in the commodity export sector and $\epsilon_t^{A^x}$ is the productivity shock in the sector.

Commodity exporters firms maximize their profits following:

$$\Gamma_t^x = s_t p_t^x y_t^x - u_t^x k_{t-1}^x, \tag{11}$$

where p_t^x is the export price and the cost of capital is given by

$$u_t^x = \alpha_x \frac{s_t p_t^x}{p_t} \frac{y_t^x}{k_{t-1}^x}. \tag{12}$$

Finally, solving the problem of the firm, we have that the Tobin's Q of the commodities export firms is

$$\lambda_t \left(1 + \Phi'_{x,t} \right) = \beta E_t \left(\lambda_{t+1} X_{t+1} u_{t+1}^x + 1 - \delta + \Phi'_{x,t+1} \right), \tag{13}$$

where $X_{t+1} = \frac{s_t p_t^x}{p_t}$.

2.3 Manufacturing Firms

The firms use intermediate goods that are produced with a combination of imported goods and labor. These firms follow a production function defined by

$$y_t^w = A_t \left(k_{t-1}\right)^{\alpha_k} m_t^{\alpha_m} \left(h_t\right)^{1-\alpha_k-\alpha_m}, \tag{14}$$

where k_{t-1} is the stock of capital of the manufactured goods producer, h_t is the number of hours used in this productive sector, α_m is the participation of the imported goods in the production function of the manufactured goods and α_k is the participation of the capital in the production function. Further, A_t is the productivity of the manufacturing firms and follows an AR(1) dynamics such that:

$$\ln \frac{A_t}{A} = \rho_A \ln \frac{A_{t-1}}{A} + \epsilon_t^A + \lambda_{gg}\epsilon_t^{tot}, \tag{15}$$

where ρ_A is the persistence of the productivity in the manufacturing export sector firms, A is the steady state of the productivity, ϵ_t^A is the productivity shock, and λ_{gg} is the correlation between the terms of trade shock and the productivity shock; see Castillo and Rojas (2014) for empirical evidence that shows a positive correlation between total factor productivity and terms of trade shocks in Peru.

The optimal demand of imported goods (m_t) used in the production of the intermediate goods is:

$$RER_t = \alpha_k \frac{y_t^w}{m_t}, \tag{16}$$

where RER_t is the real exchange rate defined as the relative price of the consumption basket of foreign goods to domestic consumption goods, $RER_t = \frac{s_t p_t^m}{p_t}$. This relative price follows the following dynamics:

$$RER_t = \left(RER_{t-1}\right)^{\lambda_q} \left(\frac{s_t}{\left(s_{t-1}\right)}\pi_t\right)^{(1-\lambda_q)}, \tag{17}$$

where λ_q is the rigidity of the real exchange rate and π_t is the domestic inflation rate.

The manufacturing firms maximize their profits such that:

$$\Gamma_t = p_t^w y_t^w - u_t k_{t-1} - s_t p_t^m m_t - w_t h_t, \tag{18}$$

where p_t^w is the wholesale price of manufacturing goods, whereas u_t is the cost of capital defined by

$$\frac{u_t}{p_t^w} = \alpha_k \frac{y_t^w}{k_{t-1}}.$$

Solving the problem of the firm, we define the Tobin's Q of the manufacturing firms as:

$$\lambda_t (1+\Phi_t) = \beta E_t \left[\lambda_{t+1} \left(\frac{u_{t+1}}{p^w_{t+1}} + 1 - \delta + \Phi'_{t+1} \right) \right]; \tag{19}$$

and the optimal demand for labor in the manufacturing goods producing sector is:

$$(1-\alpha_m-\alpha_k) \frac{y^w_t}{h_t} = \frac{w_t}{p^w_t}. \tag{20}$$

2.4 Final Goods Producers

The manufacturing goods are transformed into intermediate differentiated goods using a one to one technology. Firm z production function is described next:

$$y_t(z) = y^w_t(z). \tag{21}$$

There is a mass of size 1 of intermediate good producers that sell inputs to final good firms. Intermediate goods are transformed into final goods using the following CES aggregator function:

$$y_t = \left[\int_0^1 y_t(z)^{\frac{\varepsilon-1}{\varepsilon}} dz \right]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{22}$$

where, $\varepsilon > 1$ represents the elasticity of substitution among intermediate inputs. Firms producing intermediate inputs set prices optimally taking into account nominal rigidities a la Calvo (1983). The optimal price of consumption goods is therefore determined by the cost of producing optimally one unit of final good and it is given by the following equation:

$$p_t = \left[\int_0^1 p_t(z)^{1-\varepsilon} dz \right]^{\frac{1}{1-\varepsilon}}. \tag{23}$$

Cost minimizing implies that the demand of final good producers for each type of intermediate good is given by:

$$y_t(z) = \left(\frac{p_t(z)}{p_t} \right)^{-\varepsilon} y_t, \tag{24}$$

where y_t stands for the aggregate demand of final goods, which is determined by the demand generated from household consumption, investment of exporting and manufacturing goods, and exports and adjustment costs, as follows:

$$y_t = (c_t + i^x_t + \Phi_{x,t+1} + i_t + \Phi_{t+1}) + x^{NT}_t. \tag{25}$$

where x^{NT}_t is the non-traditional exports.

2.5 The Phillips Curve

Intermediate goods producers set prices optimally. Each period t intermediate goods producers face an exogenous probability of changing prices given by $(1-\phi)$. Following Calvo (1983) and Yun (1996), we assume that this probability is independent of the price level chosen by the firm in previous periods and on the last time the firm changed its price. Also, there is an exogenous indexation rule by which, prices increase automatically by a fraction $\gamma < 1$ of the previous period inflation rate. Under these conditions a typical intermediate goods firm chooses an optimal price $p_t^o(z)$ to maximize the present discounted value of its expected flow of profits, given by:

$$E_t\left[\sum_{k=0}^{\infty}(\phi\beta)^k\left(\lambda_{t+k}\left(\frac{p_t^o(z)}{p_{t+k}}\left(\frac{p_{t+k-1}}{p_{t-2}}\right)^{\gamma}-mc_{t+k}\right)\tilde{y}_{t+k}\left(z\right)\right)\right]. \tag{26}$$

The inverse of the cumulative inflation rate of the consumer price index is denote by Ψ_{t+k}, which is defined as follows:

$$\Psi_{t+k}=\frac{p_t}{p_{t+k}} \tag{27}$$

and by $\tilde{y}_{t+k}(z)$ the conditional demand for input z, $t+k$ periods ahead on $p_t^o(z)$:

$$\tilde{y}_{t+k}\left(z\right)=\left(\frac{p_t^o\left(z\right)}{p_t}\pi_{t-1}^{\gamma}\Pi_{t+k-1}^{\gamma}\right)^{-\varepsilon}\Psi_{t+k}^{-\varepsilon}y_{t+k}, \tag{28}$$

and the cumulative inflation is denoted by

$$\Pi_{t+k}=\frac{p_{t+k-1}}{p_{t-1}}. \tag{29}$$

The first order condition of the final good producers that determines the optimal price level is given by:

$$E_t\left[\sum_{k=0}^{\infty}(\phi\beta)^k\left(\lambda_{t+k}\left(\frac{p_t^o\left(z\right)}{p_t}\pi_{t-1}^{\gamma}\Pi_{t+k-1}^{\gamma}\Psi_{t+k}-\frac{\varepsilon}{\varepsilon-1}mc_{t+k}\right)\tilde{y}_{t+k}\left(z\right)\right)\right], \tag{30}$$

where mc_t is the marginal cost of manufacturing firms.

Rearranging the previous condition, we obtain the optimal price, $p_t^o(z)$:

$$\frac{p_t^o\left(z\right)}{p_t}\pi_{t-1}^{\gamma}=\frac{\varepsilon}{\varepsilon-1}\frac{E_t\left[\sum_{k=0}^{\infty}\left(\phi\beta\right)^k\Psi_{t+k}^{-\varepsilon}\Pi_{t+k-1}^{-\gamma\varepsilon}\lambda_{t+k}mc_{t+k}y_{t+k}\right]}{E_t\left[\sum_{k=0}^{\infty}\left(\phi\beta\right)^k\lambda_{t+k}y_{t+k}\Psi_{t+k}^{(1-\varepsilon)}\Pi_{t+k-1}^{\gamma(1-\varepsilon)}\right]}=\frac{V_t^N}{V_t^D}. \tag{31}$$

Using the law of large numbers, the aggregate price level of final goods can be written as follows:

$$p_t^{1-\varepsilon}=\phi p_{t-1}^{1-\varepsilon}+\left(1-\phi\right)p_t^o(z)^{1-\varepsilon}. \tag{32}$$

Dividing the previous equation by p_t we obtain:

$$1 = \phi \Pi_t^{\varepsilon-1} + (1-\phi) \frac{p_t^o(z)}{p_t}^{1-\varepsilon}. \tag{33}$$

Following Benigno and Woodford (2005), we can write this first order condition of the firms problem recursively using the two auxiliary variables $V_t^N$and V_t^D:

$$\phi \pi_t^{\varepsilon-1} = 1 - (1-\phi) \left(\frac{V_t^N}{V_t^D} \pi_{t-1}^{-\gamma} \right)^{1-\varepsilon}, \tag{34}$$

where γ is a parameter the controls the the persistence of inflation and V_t^N and V_t^D are given by

$$V_t^N = \Lambda_t Y_t \mu mc_t(z) + \beta \phi E_t \left(\pi_{t+1}^{\varepsilon} V_{t+1}^N \pi_t^{-\varepsilon\gamma} \right), \tag{35}$$

$$V_t^D = \Lambda_t Y_t + \beta \phi E_t \left(\pi_{t+1}^{1-\varepsilon} V_{t+1}^D \pi_t^{(1-\varepsilon)\gamma} \right), \tag{36}$$

where Λ_t is the firm's stochastic discount factor and μ is the firm's mark up. These three last equations are the non-linear representation of the Phillips Curve.

2.6 Foreign Sector

The equation that determines the balance of payments is obtained by aggregating the consumption demand, the investment and the exports of manufactured goods. This gives:

$$\frac{xn_t}{p_t} = y_t + \frac{s_t p_t^x}{p_t} y_t^x - \frac{s_t p_t^m}{p_t} m_t - \left(c_t + i_t^x + \Phi_x \left(k_{t+1}^x - k_t^x \right) + i_t + \Phi \left(k_{t+1} - k_t \right) \right), \tag{37}$$

where xn_t represents the net exports.

The net asset position is:

$$\frac{s_t d_t}{p_t} + \frac{s_t}{p_t} \frac{p_{t-1}}{s_{t-1}} \left(\frac{s_{t-1} FX_{t-1}}{p_{t-1}} \right) = \frac{s_t}{p_t} \frac{p_{t-1}}{s_{t-1}} \frac{s_{t-1} d_{t-1}}{p_{t-1}} (1 + r_{t-1}) + \frac{s_t FX_t}{p_t} - \frac{xn_t}{p_t}, \tag{38}$$

where FX is the foreign exchange intervention of the Central Bank. The non-traditional exports are:

$$x_t^{NT} = (RER_t)^{\xi} C_t^*, \tag{39}$$

where ξ is the elasticity of the non-traditional exports, and C_t^* is the foreign demand of goods.

The terms of trade are defined as follows:

$$tot_t = \frac{p_t^x}{p_t^m}, \tag{40}$$

and the dynamic of the terms of trade is an AR(1) equation:

$$\ln \frac{tot_t}{tot} = \rho_{tot} \ln \frac{tot_{t-1}}{tot} + \epsilon_t^{tot}, \tag{41}$$

where ρ_{tot} is the persistence of the terms of trade, tot is the steady state of the terms of trade and ϵ_t^{tot} is a shock of terms of trade.

The relative price of exported goods are:

$$\frac{s_t p_t^x}{p_t} = x_t = x_{t-1}^{\lambda_x} \left[\frac{s_t p_t^x}{s_{t-1} p_{t-1}^x \pi_t} \right]^{(1-\lambda_x)},$$

where λ_x is the rigidity of the relative price of exported goods.

We follow Adolfson et at. (2008) in the inclusion of the expected change in the exchange rate $E_t\left(\frac{s_{t+1}}{s_t}\right)$ in the modified uncovered interest rate parity equation equation. This is based on the observation that risk premium are strongly negatively correlated with the expected change in the exchange rate, see Duarte and Stockman (2005) and Fama (1984). This pattern is often referred to as the "forward premium puzzle". In this way, we can capture the hump-shaped response of the real exchange rate after a shock to monetary policy, which is commonly found in estimated VARs, see Eichenbaum and Evans (1995) and Faust and Rogers (2003). The modify uncovered interest rate parity that captures this empirical feature implies a gradual and less than complete response of the exchange rate to changes in the spread between domestic and foreign interest rates, which we parameterize as follows:

$$\left(\frac{s_t}{s_{t-1}}\right)^{\lambda_s} = E_t\left(\frac{s_{t+1}}{s_t}\right)\left(\frac{1+i_r^f}{1+r_t}\right)^{1-\lambda_s}. \tag{42}$$

The country risk premium is given by

$$r_t^f = r_t^* + \psi \exp(\frac{d_t}{d} - 1) - \lambda_{x_i} \log(\frac{tot_t}{tot}) + \varepsilon_t^{rf}, \tag{43}$$

where r_t^* is the international interest rate, ψ is the risk premium debt elasticity, λ_{x_i} is the risk premium terms of trade elasticity and ϵ^{rf} is country risk premium shock that evolves following a law of movement given by

$$\varepsilon_t^{rf} = \rho_{rf} \varepsilon_{t-1}^{rf} + \epsilon_{t,RR}, \tag{44}$$

where ρ_{rf} is the persistence of the risk premium shock and $\epsilon_{t,RR}$ represents the innovation of the risk premium shock.

2.7 Gross Domestic Product and Total Investment

We define the GDP as

$$y_t^{GDP} = p y_t + p^x y_t^x, \tag{45}$$

where p_t is the price of manufactured goods in steady state, p^x is the export price of commodities in steady state. The total investment is given by

$$i_t = i_t^x + i_t^m. \tag{46}$$

2.8 Monetary Policy

We assume that the Central Bank adjusts its interest rate in response to changes in inflation rate, movements in the nominal exchange rate and the fluctuations in the output gap[2] such that:

$$(1 + r_t) = \left(\frac{1}{\beta}\right)^{1-\rho_R} (1 + r_{t-1})^{\rho_R} (\Pi_t)^{(1-\rho_R)\phi_\pi} y_t^{GDP^{(1-\rho_R)\phi_y}} \left(\frac{s_t}{s_{t-1}}\right)^{(1-\rho_R)\phi_e}. \tag{47}$$

The coefficient $\phi_\pi > 1$ measures the response of the interest rate to changes in the inflation rate, $\phi_e > 0$ is the quantifies the response of the interest rates to changes in the nominal exchange rate and $\phi_y > 0$ measures the response of the interest rate to changes in the output. The persistence of the interest rate is captured by $0 < \rho_R < 1$. One of the purposes of this study is to evaluate the response of the monetary policy rate to exchange rate movements by analyzing if $\phi_e > 0$.

Additionally, we consider that the Central Bank intervenes in the FX market following a lean against the wind type of rule for FX intervention:

$$\frac{FX_t}{FX} = \left(\frac{s_t}{s_{t-1}}\right)^{-\delta_{fx}} exp(\epsilon_t^{fx}), \tag{48}$$

where FX represents the steady-state value of foreign exchange reserves, and δ_{fx} captures the extent in which the Central Bank responds to exchange rate movements.

FX intervention affects the net foreign asset position of the economy, which in turn has a direct impact on the country risk premium, and through the modified UIP on the exchange rate.

3 Empirical Results

3.1 Choice of Priors

Parameters associated to the steady-state of the model are calibrated to the Peruvian economy using quarterly data (see Table 1). The remaining set of parameters were estimated using Bayesian methods. Most of the priors are obtained from the BCRP macroeconomic quarterly model, see Salas (2011) and Vega et al. (2009) are in line with the literature on small open economies exposed to commodity prices shocks. For standard deviations of structural shocks and for parameters associated with monetary policy we use a Inverse Gamma distribution as prior. In addition, for persistence parameters we use Beta distributions as priors.

[2]Defined as the difference between the real GDP and the trend of the GDP.

3.2 Data Description

The observable variables used in the estimation are real gross domestic product (GDP), total exports, real private consumption, consumer price index (CPI), monetary policy rate, nominal exchange rate and terms of trade. The time series of monetary policy interest rate is constructed using the average interbank rate in domestic currency from 1997 to 2003 and, from 2004 onwards, we use the BCRP's monetary policy rate. GDP, consumption, exports and CPI inflation are seasonally adjusted and introduced in the model as the first log difference in deviation from its mean. The data is at quarterly frequency from 1997Q1 to 2017Q4 and it was obtained from the statistics published at the webpage of the BCRP.

3.3 Estimation Results

We estimate four different versions of the baseline model that differ in the restrictions imposed to the Taylor rule and whether or not the FX intervention is active (see Table 2). Model 1 is the less restrictive one, which considers a Taylor rule that responds to GDP growth, inflation rate, changes in the exchange rate ($\phi_e > 0$) and an active FX intervention rule ($\delta_{fx} > 0$). The Model 2 contemplates the exchange rate in the Taylor rule ($\phi_e > 0$) and impose the restriction that the Central Bank does not intervene in the FX market ($\delta_{fx} = 0$). The Model 3, imposes the restriction that the Taylor rule does not respond to changes in the exchange rate ($\phi_e = 0$), but the Central Bank intervenes in the FX market ($\delta_{fx} > 0$). Finally, the Model 4 considers a Taylor rule that does not respond to exchange rate movements ($\phi_e = 0$) and a Central Bank that does not intervene in the FX market ($\delta_{fx} = 0$).

We split the sample into two subsamples. The first one, from 1997 to 2003, which corresponds to the pre-IT regime. The second sample, from 2004 to 2017, corresponds to the period in which Peru follows an IT regime. Table 3 panel (a) and (b) present the marginal log density and the Bayes Factor of the four models in both subsamples. We use the marginal log density to rank the estimated models. First, we find that for the pre-IT and for the IT regimes, the model that clearly performs better in terms of marginal log density is Model 3. This result is consistent with IT plus control risk framework that the BCRP uses to implement its monetary policy. In this framework, the BCRP uses the short-term interest rate to anchor inflation expectations and FX interventions and reserve requirements to limit risks associated to financial dollarization[3]. In the pre-IT period, Model 2 is the version of the model with the lowest marginal log density. This model considers that the BCRP does not intervene in the FX market ($\delta_{fx} = 0$). Instead, the BCRP uses the interest rate to respond to exchange rate fluctuations, which further support the importance of FX intervention to properly characterize monetary policy in Peru. In the IT period, Model 4 is the version with the lowest marginal log density which considers that the BCRP does no include changes in the exchange rate in the monetary policy rule ($\phi_e = 0$) and does not intervene in the FX market ($\delta_{fx} = 0$).

Figure 1 shows the identification strength-plot. The bar charts depict the identification strength of the parameters based on the Fisher information matrix normalized by either the

[3] See Rossini and Santos (2015) for a detailed description of the BCRP monetary policy framework.

parameter at the prior mean (blue bars) or by the standard deviation at the prior mean (orange bars), see Ratto and Iskrev (2011). Intuitively, the bars represent the normalized curvature of the log likelihood function at the prior mean in the direction of the parameter. Note that the graphs generally use a log-scale except for parameters that are unidentified, which are shown with a bar length of exactly 0 as the likelihood function is flat in this direction. In contrast, the larger the value, the stronger is the identification. The parameters are ordered in the direction of increasing identification strength relative to the parameter value. As this Figure shows, all the estimated parameters are identified in the Jacobian of mean and spectrum, see Qu and Tkachenko (2012), and according to the Jacobian of first two moments, see Iskrev (2010).

Tables 5 and 7 show the posterior mode of the estimated parameters of Models 3 and 4. We compare these two models as Model 3 is the best model in terms of log density and Model 4 is the most restrictive model. In this way, we can illustrate more precisely the role that FX intervention plays in the propagation mechanism of macroeconomic shocks. A second interesting result is that, in both subsamples, the size of the response of the interest rate to inflation (ϕ_π) is close to 2. This value is consistent with an interest rate rule that satisfies the Taylor principle, which guarantees that the inflation rate is anchored to the Central Bank inflation target, a finding that is consistent with the performance of inflation in Peru since the adoption of the IT framework[4]. A third result is that the response of interest rate to the GDP gap (ϕ_y) is greater than 1 which is consistent with a counter-cyclical response of the monetary policy, particularly in case of aggregate demand shocks.

A fourth result shows that the response of FX interventions to fluctuations in the exchange rate (δ_{fx}) has become stronger during the IT period. In fact, in the IT period, this parameter is almost nine times larger than in the pre-IT period. This finding is consistent with a more active participation of the BCRP in the FX market during the IT regime or a better signalling of the lean against the wind type of FX intervention. Since 2004, Peru faced an increasing volatility of capital flows as gradually gained access to the global financial markets and it became more active in the use of macro-prudential tools, including a lean against the wind type FX intervention strategy. During 2007Q1-2008Q2, the BCRP bought foreign currency for an amount equivalent to 18.5% of GDP to smooth the impact on the domestic economy of abundant capital inflows, whereas during the financial crisis (2008Q3-2009Q1) the Central Bank sold foreign currency for an amount equivalent to 8.4% of GDP, a response that contributed to limit the impact of the sudden stop of capital flows that the global financial generated on domestic credit conditions[5]. It is important to highlight that the estimated FX rule is coherent with a floating exchange rate regime where the BCRP intervenes aiming at reducing the volatility of the exchange rate. Since Peru adopted a floating exchange regime in 1990 (Vega and Lahura, 2012) the BCRP has continued using FX interventions to reduce the risk associated to financial dollarization and the spillover effects of the global financial cycle into domestic credit conditions[6].

[4] Average inflation in Peru since 2001 to 2017 is 2.6%, within its inflation target of 1%-3%.

[5] See Arena and Tuesta (1999), Humala and Rodríguez (2010) and Rossini and Vega (2008) for an assessment of the FX intervention policy of the BCRP.

[6] See Armas et al. (2001) and Rossini (2002) for a detailed discussion of the transition of Peru to the IT framework.

3.4 Bayesian Impulse Response Functions

We present the Bayesian impulse response functions (IRFs) of the best estimated version of the baseline model (Model 3) in comparison to the most restrictive version of the baseline model (Model 4) for four structural shocks: productivity of the manufacturing sector, cost-push, risk premium and terms of trade shocks. In this way we can highlight the effects of FX intervention in the dynamics of the BCRP policy response.

Figure 2 shows the response of a selected set of variables to an increase in productivity of the manufacturing sector. Panel (a) shows the IRFs for the pre-IT regime, whereas panel (b) shows the IRFs during the IT regime period. As panel (a) shows, an increase in productivity generates a persistent increase in GDP, consumption, and investment. In contrast, the inflation rate decreases as marginal costs falls and trade balance improves, which triggers a reduction in the net foreign debt position and a lower country risk premium that appreciate the domestic currency. As the inflation weight on the Taylor rule is larger than the weight of the GDP growth, the fall in the inflation rate more than offset the effect of the increase in the GDP growth on the Taylor rule. Consequently, the BCRP responds by cutting its policy rate and purchasing in the FX market. As a result, in Model 3, the nominal exchange rate falls less than the inflation rate and the appreciation of the domestic currency is mitigated, which generates a real depreciation of domestic currency.

Figure 2 panel (b) shows the response of the economy during the IT regime, which are qualitatively similar to the ones during the pre-IT regime but are quantitatively different. The GDP and consumption respond to a lesser extent to a productivity shock of the same magnitude than in the pre-IT period. Also, the nominal exchange rate falls less and the real exchange rate increases more. A key difference between the two periods is the coefficient associated with the response of the FX intervention to changes in exchange rate (δ_{fx}). During the pre-IT period, this coefficient is less than 1, whereas during the IT regime period for the same model is 5.3. This different response implies that the nominal exchange rate and the inflation rate fall less during the IT period, which induces the Central Bank to cut to a lesser extent its interest rate. The smaller cut in the policy rate, in turn, generates a smaller increase of GDP, aggregate consumption and investment in comparison with the ones observed during the pre-IT period. Overall, these results shows that the policy response of the BCRP generates lower GDP and inflation volatility in response to productivity shocks during the IT period.

Comparing the response of the economy to a productivity shock in Model 3 to those in Model 4, it is clear that the key difference is the response of the nominal and the real exchange rate. In Model 4 ($\delta_{fx} = 0$) a positive productivity shock generates a larger nominal appreciation and a smaller real depreciation of the domestic currency whereas in the Model 3 ($\delta_{fx} > 0$), this shock generates a larger real depreciation of the domestic currency, a smaller reduction in inflation and interest rate, which generates a smaller expansion in consumption, and GDP in comparison to Model 4. From this results it is clear that the use of FX intervention by BCRP reduces the volatility of output and the inflation rate in response to domestic productivity shocks.

Figure 3 panel (a), shows the response of the economy to a persistent cost-push shock during the pre-IT regime. The inflation rate increases sharply and the BCRP rises its interest rate to maintain the inflation expectations anchored. Therefore, consumption, investment and GDP fall. As output declines, external net borrowing increases and consequently the country risk premium rises pushing the exchange rate upwards. FX intervention prevents a large nominal depreciation, which together with higher inflation result in a fall in the real exchange rate, which generates a larger trade deficit.

During the IT regime period (see Figure 3 panel (b)), the Central Bank uses more strongly FX interventions, which prevents a large depreciation of the domestic currency. In the short-term, a smaller exchange rate pass-through to inflation reduces the need of the Central Bank to increase the nominal interest rate. In fact, the Central Bank cuts its policy rate instead of increasing it. Overall, in the IT period the fall in consumption and GDP are smaller than during the pre-IT regime. In this way, the policy response of the Central Bank contributes to reduce the volatility of output and consumption in response to a cost-push shock.

Figure 4 panel (a) shows the IRFs of an increase in the risk premium during the pre-IT regime period. The nominal and the real exchange rate rises, as a result, the inflation rate jumps. The BCRP increases its interest rate to maintain the inflation rate anchored and GDP falls. The FX intervention of the BCRP smooths the depreciation of the exchange rate, therefore, the nominal and real exchange rate increase less than in Model 4. During pre-IT regime, consumption and investment do not fall in the short-term, as the depreciation of the real exchange rate boosts net exports, which compensates the negative impact of higher interest rate in consumption and investment.

Figure 4 panel (b) shows the IRFs to an unexpected increase in risk premium during the IT period. This shock negatively impact the GDP and consumption. Also generates a nominal and real depreciation of the domestic currency. The inflation rate increases in response to the higher exchange rate. As a result, the Central Bank rises its policy rate. This increase in the policy rate is larger as inflation remains elevated for a longer period of time.

Figure 5 panel (a), shows the IRFs to a positive terms of trade shock during the pre-IT regime period. This shock generates a fall in the nominal exchange rate and a trade surplus. The BCRP accumulates international reserves through FX purchases and inflation rate falls in response to a lower nominal exchange rate. However, due to BCRP's FX intervention, both the fall in the inflation rate and the appreciation of the nominal exchange rate are mitigated. As a result, the real exchange rate increases, which boosts net exports. In addition, higher terms of trade increase the profitability of the commodity sector, which in turn increases investment and generates a positive wealth effect that expands the aggregate consumption. The fall in the inflation rate more than offsets the impact of higher GDP growth rate on the Taylor rule and induces to the BCRP to cut its policy rate.

Figure 5 panel (b) shows the response of the economy to a positive terms of trade shock during the IT regime period. The IRFs show that the GDP, investment and consumption expand but to a lesser extent than during the pre-IT period. The nominal exchange rate and the inflation rate fall less than during the pre-IT period, whereas the real exchange rate depreciates more. A key difference of the response of the economy during the IT period is the stronger FX intervention and the less intense response of the nominal interest rate to GDP. A more intensive use of FX intervention limits the appreciation of the nominal exchange rate which, in turn, induces a smaller fall in inflation and a smaller cut of the interest rate. The combination of an active Taylor rule and a more intense FX intervention, generates a lower volatility in output, investment and aggregate consumption in response to terms of trade shocks.

3.5 Forecast Error Variance Decomposition (FEVD)

In Figure 6 panel (a) and (b) we present the FEVD for the GDP and in Figure 7 panel (a) and (b) the FEVD for the interest rate. A first interesting result is that the productivity shock is the most important determinant for the FEVD of GDP, during the pre-IT and IT periods. This shock explains about 40% of the variation of the FEVD of GDP in the long term in both samples. Second, the participation of terms of trade shocks has increased during the IT period, from around 10% pre-IT to almost 20% during the IT period and is one the most important sources of volatility for GDP.

In the case of the FEVD of the interest rate, the productivity shock explains 75% of the FEVD in the pre-IT period and around 65% in the IT period. This is consistent with Humala and Rodríguez (2009) who find the the natural interest rate and the observed interest rate are highly dependent on the productivity. Likewise, we find that the contribution of the terms of trade shock has almost double from the pre-IT to the post adoption IT period of the interest rate FEVD. This result is consistent with the findings of Schmitt-Grohé and Uribe (2017) which shows that the terms of trade shock are an important determinant of GDP in the Peruvian economy.

4 Conclusions

We estimate a quarterly DSGE model for a small open economy based on Schmitt-Grohé and Uribe (2017) for the Peruvian economy. The model considers households, two productive sectors, a monetary policy authority and a foreign sector. We include a Taylor rule that responds to inflation, output gap and changes in the nominal exchange rate. Additionally, we enriched the model by incorporating a explicit sterilized FX intervention rule, as in Faltermeier et al. (2017), that the Central Bank uses to reduce the volatility of the exchange rate. We estimate four different versions of the baseline model with different restrictions imposed to the Taylor rule and to FX intervention rule. We also estimate the models for two subsamples: pre-IT and IT regime periods.

We find that the best model in terms of log marginal density for the two subsamples is the Model 3, which considers that the monetary policy rate does not respond to changes in the nominal exchange rate ($\phi_e = 0$), but the BCRP intervenes in the FX market ($\delta_{fx} > 0$). We also find that the interest rate response to the inflation rate is close to 2 and the response to GDP gap is greater than 1. These results are consistent with the monetary policy framework that the BCRP has been following during the period of study. Furthermore, we find that the response of the FX intervention to changes in the nominal exchange rate (δ_{fx}) in the IT period is almost nine times bigger than in the pre-IT period. This is also coherent with the BCRP monetary and exchange operations and the adoption of the floating exchange regime.

The estimated IRFs show that BCRP's FX interventions are effective reducing the exchange rate volatility and, therefore, the inflation rate. This support the literature branch that in emerging economies, like Peru, FX interventions and IT regime contribute to the same goal of keeping the inflation rate within the inflation target.

Appendix

A Linear Model

A.1 Households

Lagrange multiplier:

$$\lambda_t = -\sigma \left(\frac{c}{c - \left(\frac{h}{\omega}\right)^{\omega}} \right) c_t + \sigma \left(\frac{h \left(\frac{h}{\omega}\right)^{\omega}}{c - \left(\frac{h}{\omega}\right)^{\omega}} \right) h_t \tag{A.1}$$

Labor supply:

$$(\omega - 1)\, h_t = w \tag{A.2}$$

Euler equation:

$$\lambda_t = \lambda_{t+1} + r_t - \pi_{t+1} \tag{A.3}$$

A.2 Commodities Export Firms

Production function of the commodities export firms:

$$y_t^x = a_x + \alpha_x k_{t-1}^x \tag{A.4}$$

Law of movement of capital:

$$k_t^x = (1 - \delta)\, k_{t-1}^x + \delta i_t^x \tag{A.5}$$

Productivity law of movement:

$$a_t^x = \rho_{A^x} a_{t-1}^x + \varepsilon_t^{A_x} \tag{A.6}$$

Cost of capital:

$$u_t^x = x_t + y - k_{t-1}^x \tag{A.7}$$

Tobin's Q:

$$\lambda_t + \Phi_{x,t} = \lambda_{t+1} + \frac{u^x}{(u^x + 1 - \delta)} \left(u_{t+1}^x\right) + \frac{\Phi_{x,t}}{(u^x + 1 - \delta)} \tag{A.8}$$

A.3 Manufacturing Firms

Production function:

$$y_t^{\omega} = a_t + \alpha_k k_{t-1} + \alpha_m m_t + (1 - \alpha_m - \alpha_k)\, h_t \tag{A.9}$$

Law of movement of capital:

$$k_t = (1 - \delta)\, k_{t-1} + \delta i_t^m \tag{A.10}$$

Productivity law of movement:

$$a_t = \rho_a a_{t-1} + \varepsilon_t^a + \lambda_{gg} \varepsilon_t^{tot} \tag{A.11}$$

Demand for imported goods:

$$m_t = y_t - RER_t + mc_t \tag{A.12}$$

Dynamic of relative prices:

$$RER_t = \lambda_q RER_{t-1} + (1 - \lambda_q)\,(s_t - \pi_t) \tag{A.13}$$

Cost of capital:

$$u_t = y_t - k_{t-1} + \alpha_k \tag{A.14}$$

Demand of labor:

$$y_t^{\omega} - h_t + \alpha_k = w \tag{A.15}$$

Tobin's Q:

$$\lambda_t + \Phi_t = \lambda_{t+1} + \frac{u}{(u + 1 - \delta)}\,(u_{t+1}) + \frac{\Phi_{t+1}}{(u + 1 - \delta)} \tag{A.16}$$

A.4 Final Good Producer

The aggregate demand for final goods is given by:

$$y_t = \left(\frac{c}{y} c_t + \frac{i}{y} i_t\right) + \Phi\,(k_t - k_{t-1}) + \Phi_t^x \left(k_t^x - k_{t-1}^x\right) + \frac{x}{y} x_t^{NT}, \tag{A.17}$$

A.5 Phillips Curve

$$\pi_t = \beta \pi_{t+1} + \frac{(1 - \beta\varepsilon)(1 - \varepsilon)}{\varepsilon} mc_t + \gamma \frac{(1 - \varepsilon)}{\varepsilon} \pi_{t-1} + \mu \tag{A.18}$$

where the firm's mark up:

$$\mu_t = \rho_u \mu_{t-1} + \varepsilon_{inv} \tag{A.19}$$

A.6 Foreign Sector

Net exports:

$$xn_t xn = y_t y + p^x y^x_t (x_t + y^x_t) - mRERm_t - c_t c - i_t i - \Phi_t - \Phi_{x,t+1} \tag{A.20}$$

Risk premium:

$$i^f_t = r^* + \psi d_t - \lambda_{xi} tot_t + \varepsilon^{rf}_t \tag{A.21}$$

Risk premium shock:

$$\varepsilon^{rf}_t = \rho_{rf} \varepsilon^{rf}_{t-1} + \varepsilon^{RR}_t \tag{A.22}$$

Net asset position:

$$\left(\frac{dRER}{dRER + xn}\right)(d_t + RER_t - FX_t) + \left(\frac{XN_t xn}{dRER + xn}\right) xn_t = d_{t-1} + FX_{t-1} + i^f_{t-1} + RER_t \tag{A.23}$$

Non-traditional exports:

$$x^{NT}_t = \xi RER_t, \tag{A.24}$$

Relative price of exports:

$$x_t = \lambda_x x_{t-1} + (1 - \lambda_x)\left(ds_t + p^x_t - p^x_{t-1} - \pi_t\right) \tag{A.25}$$

Definition of the terms of trade:

$$tot_t = p^x_t \tag{A.26}$$

Law of movement of the terms of trade:

$$tot_t = \rho_{tot} tot_{t-1} + \varepsilon^{tot}_t \tag{A.27}$$

A.7 Gross Domestic Product

$$y^{GDP}_t = \left(\frac{p^x y^x}{p^x y^x + y^\omega}\right) y^x_t + \left(\frac{y^\omega}{p^x y^x + y^\omega}\right) y^\omega_t \tag{A.28}$$

A.8 Total Investment

$$i_t = \left(\frac{i^x}{i^x + i^m}\right) i^x_t + \left(1 - \frac{i^x}{i^x + i^m}\right) i^m_t \tag{A.29}$$

A.9 Monetary Policy

Monetary policy rule:

$$r_t = \rho_r r_{t-1} + (1 - \rho_r) (\phi_\pi \pi_{t+1} + \phi_y y_t + \phi_e s_t) \tag{A.30}$$

Modified uncovered interest rate parity:

$$\lambda_s s_t = s_{t+1} + (1 - \lambda_s) \left(i_t^f - r_t \right) \tag{A.31}$$

Intervention rule:

$$FX = -\lambda_{fx} s_t + \varepsilon_t^{fx} \tag{A.32}$$

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Table 1: Priors Distributions

Parameters	Description	Distribution	Prior Mean	Prior Std. Dev.
ρ_{rf}	Persistence of the shock of the country risk premium	Inverse Gamma	0.65	0.10
δ_{fx}	Extent in which the Central Bank responds to exchange rate movements through FX interventions	Inverse Gamma	0.70	2.00
ρ_R	Persistence of the interest rate	Inverse Gamma	0.30	0.01
Φ_x	Capital adjustment cost function of the commodities export sector	Inverse Gamma	0.80	0.20
Φ	Capital adjustment cost function of the manufacturing export sector	Inverse Gamma	1.50	0.15
ψ	Risk premium and debt elasticity	Beta	0.30	0.10
ω	Inverse of the labor supply elasticity	Inverse Gamma	2.30	0.20
ϕ_e	Response of the monetary policy rate to changes in the exchange rate	Inverse Gamma	0.70	0.15
ϕ_y	Response of the monetary policy rate to changes in the GDP	Inverse Gamma	1.30	0.10
ϕ_π	Response of the monetary policy rate to inflation	Inverse Gamma	2.20	0.01
λ_q	Persistence of the real exchange rate	Beta	0.36	0.10
λ_s	Degree of exchange rate stickiness	Beta	0.60	0.20
λ_{gg}	Correlation between terms of trade shocks and productivity of the manufacturing sector shocks	Beta	0.70	0.10
ρ_{tot}	Persistence of the terms of trade	Beta	0.95	0.01
ρ_{A_x}	Persistence of the productivity in the commodity export sector	Beta	0.83	0.01
ρ_A	Persistence of the productivity in the manufacturing export sector	Beta	0.80	0.10
$\sigma^{\varepsilon_{RR}}$	Standard deviation of the premium risk shock	Inverse Gamma	0.01	2.00
$\sigma^{\varepsilon_{tot}}$	Standard deviation of the terms of trade shock	Inverse Gamma	0.30	2.00
$\sigma^{\varepsilon_{A^x}}$	Standard deviation of the productivity in the commodity export sector shock	Inverse Gamma	0.01	2.00
$\sigma^{\varepsilon_{YY}}$	Standard deviation of the measurement error of the GDP	Inverse Gamma	0.01	2.00
$\sigma^{\varepsilon_{AA}}$	Standard deviation of the productivity in the manufacturing export sector shock	Inverse Gamma	0.10	2.00
$\sigma^{\varepsilon_{INV}}$	Standard deviation of the margin shock	Inverse Gamma	0.01	2.00
$\sigma^{\varepsilon_{CC}}$	Standard deviation of the measurement error of consumption	Inverse Gamma	0.01	2.00
$\sigma^{\varepsilon_{YY_x}}$	Standard deviation of the measurement error of the production in the commodity export sector	Inverse Gamma	0.01	2.00

Table 2: Description of Model Versions

Model	Description	
1	The Central Bank considers changes in the nominal exchange rate in the monetary policy rule and intervenes in the FX market	$\phi_e > 0$ $\delta_{fx} > 0$
2	The Central Bank considers changes in the nominal exchange rate in the monetary policy rule and does not intervene in the FX market	$\phi_e > 0$ $\delta_{fx} = 0$
3	The Central Bank does not consider changes in the nominal exchange rate in the monetary policy rule and intervenes in the FX market	$\phi_e = 0$ $\delta_{fx} > 0$
4	The Central Bank does not consider changes in the nominal exchange rate in the monetary policy rule and does not intervene in the FX market	$\phi_e = 0$ $\delta_{fx} = 0$

Table 3: Estimated Model Versions

(a) Pre-IT period: 1997Q1-2003Q4

Model	1	2	3	4
Log marginal density	280.87	269.90	284.25	271.08
Bayes Factor	2E+04	3E-01	5E+05	1E+00

(b) Post IT period: 2004Q1-2017Q4

Model	1	2	3	4
Log marginal density	655.25	633.05	662.34	629.73
Bayes Factor	1E+11	3E+01	1E+14	1E+00

Note: The prior density over the model is the same for the four model specifications. The Bayes Factor is calculated against Model 4.

Table 4: Posterior Estimation, Pre-IT Period: 1997Q1-2003Q4

Parameters	Model 1				Model 2			
	Posterior Mean	Lower Credibility Band	Upper Credibility Band	Posterior Std. Dev.	Posterior Mean	Lower Credibility Band	Upper Credibility Band	Posterior Std. Dev.
ρ_{rf}	0.68	0.51	0.83	0.10	0.61	0.50	0.74	0.07
δ_{fx}	1.04	0.53	1.59	0.33	-	-	-	-
ρ_R	0.30	0.29	0.32	0.01	0.30	0.29	0.32	0.01
Φ_x	0.80	0.49	1.10	0.24	0.71	0.48	0.95	0.16
Φ	1.48	1.24	1.71	0.15	1.41	1.20	1.62	0.13
ψ	0.28	0.09	0.43	0.10	0.09	0.01	0.19	0.06
ω	2.26	1.95	2.57	0.19	2.12	1.85	2.38	0.17
ϕ_e	0.62	0.44	0.78	0.11	0.59	0.42	0.76	0.11
ϕ_y	1.57	1.36	1.78	0.13	1.58	1.36	1.80	0.14
λ_q	0.38	0.21	0.55	0.11	0.38	0.22	0.54	0.10
λ_s	0.77	0.65	0.88	0.07	0.44	0.24	0.64	0.12
λ_{gg}	0.58	0.39	0.77	0.12	0.55	0.35	0.74	0.12
ρ_{A_x}	0.83	0.69	0.98	0.09	0.79	0.63	0.96	0.11
ρ_A	0.85	0.82	0.89	0.02	0.90	0.87	0.94	0.02
ϕ_π	1.97	1.86	2.10	0.07	1.96	1.82	2.09	0.08
$\sigma^{\varepsilon_{RR}}$	0.01	0.00	0.02	0.01	0.00	0.00	0.01	0.00
$\sigma^{\varepsilon_{TOT}}$	0.07	0.05	0.08	0.01	0.07	0.05	0.08	0.01
$\sigma^{\varepsilon_{A^x}}$	0.02	0.00	0.03	0.01	0.01	0.00	0.01	0.00
$\sigma^{\varepsilon_{YY}}$	0.03	0.02	0.04	0.00	0.03	0.02	0.04	0.00
$\sigma^{\varepsilon_{AA}}$	0.08	0.06	0.10	0.01	0.07	0.05	0.09	0.01
$\sigma^{\varepsilon_{INV}}$	0.14	0.10	0.17	0.02	0.13	0.10	0.15	0.02
$\sigma^{\varepsilon_{CC}}$	0.02	0.02	0.03	0.00	0.03	0.02	0.03	0.00
$\sigma^{\varepsilon_{YY_x}}$	0.05	0.04	0.07	0.01	0.05	0.04	0.06	0.01

Table 5: Posterior Estimation, Pre-IT Period: 1997Q1-2003Q4

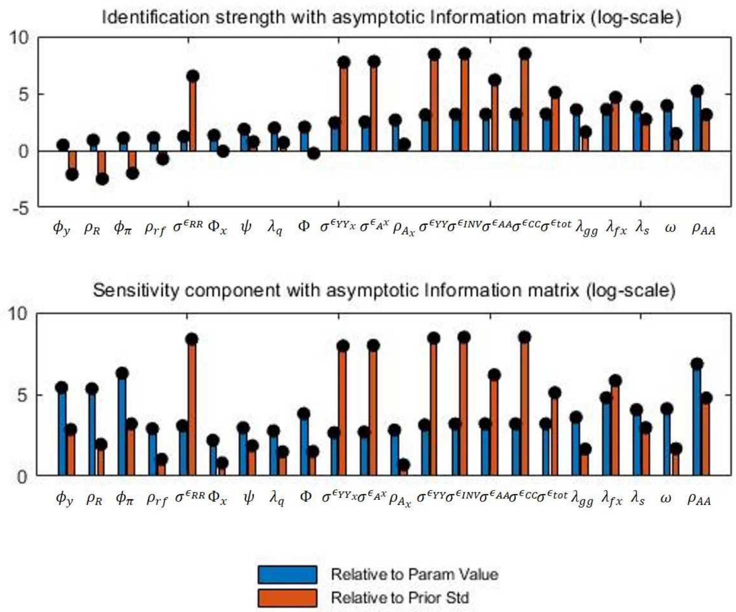
Parameters	Model 3				Model 4			
	Posterior Mean	Lower Credibility Band	Upper Credibility Band	Posterior Std. Dev.	Posterior Mean	Lower Credibility Band	Upper Credibility Band	Posterior Std. Dev.
ρ_{rf}	0.65	0.49	0.81	0.10	0.59	0.46	0.72	0.08
δ_{fx}	0.60	0.33	0.85	0.17	-	-	-	-
ρ_R	0.30	0.28	0.32	0.01	0.30	0.29	0.32	0.01
Φ_x	0.76	0.53	1.02	0.16	0.75	0.46	1.02	0.19
Φ	1.45	1.24	1.68	0.14	1.43	1.22	1.65	0.13
ψ	0.24	0.10	0.39	0.09	0.15	0.03	0.27	0.07
ω	2.30	1.98	2.61	0.20	2.24	1.93	2.55	0.19
ϕ_y	1.54	1.34	1.74	0.12	1.54	1.34	1.74	0.13
ϕ_e	-	-	-	-	-	-	-	-
λ_q	0.37	0.20	0.54	0.10	0.38	0.21	0.55	0.10
λ_s	0.61	0.47	0.74	0.08	0.24	0.08	0.41	0.10
λ_{gg}	0.54	0.35	0.72	0.11	0.49	0.32	0.68	0.11
ρ_{A_x}	0.81	0.68	0.97	0.09	0.76	0.57	0.94	0.11
ρ_A	0.87	0.83	0.90	0.02	0.92	0.91	0.94	0.01
ϕ_π	1.98	1.86	2.10	0.08	2.00	1.87	2.12	0.08
$\sigma^{\varepsilon_{RR}}$	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
$\sigma^{\varepsilon_{TOT}}$	0.07	0.05	0.08	0.01	0.07	0.05	0.08	0.01
$\sigma^{\varepsilon_{A^x}}$	0.01	0.00	0.02	0.00	0.00	0.00	0.01	0.00
$\sigma^{\varepsilon_{YY}}$	0.03	0.02	0.04	0.00	0.03	0.02	0.04	0.00
$\sigma^{\varepsilon_{AA}}$	0.07	0.05	0.08	0.01	0.05	0.04	0.07	0.01
$\sigma^{\varepsilon_{INV}}$	0.13	0.10	0.15	0.02	0.12	0.09	0.14	0.02
$\sigma^{\varepsilon_{CC}}$	0.02	0.02	0.02	0.00	0.02	0.02	0.03	0.00
$\sigma^{\varepsilon_{YY_x}}$	0.05	0.04	0.06	0.01	0.05	0.04	0.06	0.01

Table 6: Posterior Estimation, IT Period: 2004Q1-2017Q4

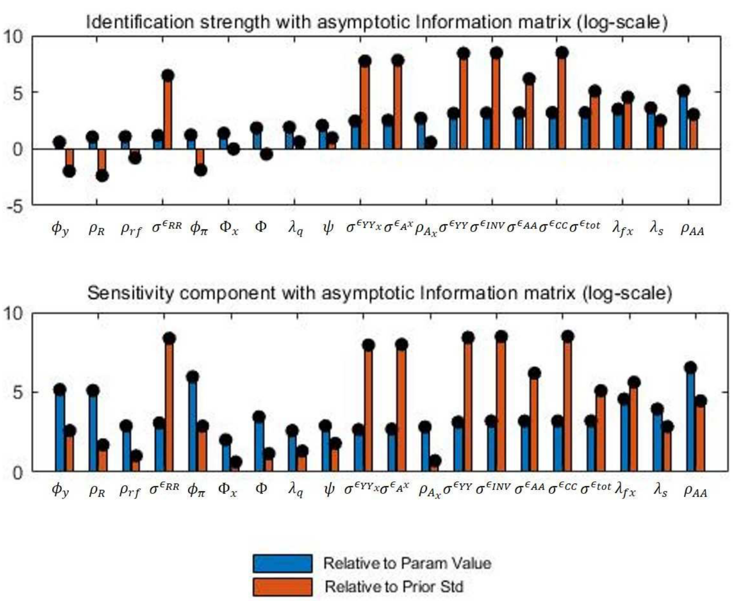
Parameters	Model 1				Model 2			
	Posterior Mean	Lower Credibility Band	Upper Credibility Band	Posterior Std. Dev.	Posterior Mean	Lower Credibility Band	Upper Credibility Band	Posterior Std. Dev.
ρ_{rf}	0.63	0.50	0.75	0.08	0.70	0.53	0.87	0.10
δ_{fx}	14.53	1.76	29.33	11.15	-	-	-	-
ρ_R	0.30	0.29	0.32	0.01	0.30	0.28	0.32	0.01
Φ_x	1.13	0.51	1.74	0.56	1.02	0.58	1.53	0.32
Φ	1.56	1.29	1.82	0.17	1.49	1.26	1.70	0.14
ψ	0.31	0.14	0.46	0.10	0.03	0.01	0.07	0.02
ϕ_e	0.54	0.41	0.68	0.08	0.61	0.47	0.74	0.09
ϕ_y	1.68	1.44	1.91	0.14	1.60	1.40	1.82	0.13
λ_q	0.33	0.20	0.48	0.09	0.36	0.18	0.52	0.10
λ_s	0.77	0.55	0.91	0.13	0.89	0.84	0.94	0.03
ρ_{A_x}	0.83	0.68	0.97	0.10	0.87	0.76	0.98	0.07
ρ_A	0.75	0.71	0.79	0.03	0.74	0.71	0.78	0.02
ϕ_π	1.97	1.84	2.10	0.08	1.99	1.88	2.12	0.07
$\sigma^{\varepsilon_{RR}}$	0.13	0.02	0.25	0.09	0.02	0.01	0.03	0.01
$\sigma^{\varepsilon_{TOT}}$	0.12	0.10	0.13	0.01	0.12	0.10	0.13	0.01
$\sigma^{\varepsilon_{A^x}}$	0.01	0.00	0.02	0.01	0.02	0.00	0.02	0.01
$\sigma^{\varepsilon_{YY}}$	0.02	0.01	0.02	0.00	0.02	0.01	0.02	0.00
$\sigma^{\varepsilon_{AA}}$	0.09	0.07	0.10	0.01	0.09	0.07	0.10	0.01
$\sigma^{\varepsilon_{INV}}$	0.13	0.11	0.15	0.01	0.13	0.11	0.15	0.01
$\sigma^{\varepsilon_{CC}}$	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00
$\sigma^{\varepsilon_{YY_x}}$	0.03	0.03	0.04	0.00	0.03	0.03	0.04	0.00

Table 7: Posterior Estimation, IT Period: 2004Q1-2017Q4

Parameters	Model 3				Model 4			
	Posterior Mean	Lower Credibility Band	Upper Credibility Band	Posterior Std. Dev.	Posterior Mean	Lower Credibility Band	Upper Credibility Band	Posterior Std. Dev.
ρ_{rf}	0.65	0.51	0.80	0.09	0.63	0.50	0.77	0.08
δ_{fx}	5.30	1.99	9.13	2.38	-	-	-	-
ρ_R	0.30	0.29	0.32	0.01	0.30	0.28	0.31	0.01
Φ_x	1.02	0.56	1.53	0.33	1.11	0.55	1.68	0.38
Φ	1.53	1.28	1.80	0.16	1.52	1.29	1.78	0.15
ψ	0.23	0.09	0.35	0.09	0.02	0.00	0.03	0.01
ϕ_e	-	-	-	-	-	-	-	-
ϕ_y	1.64	1.42	1.86	0.14	1.56	1.37	1.77	0.13
λ_q	0.35	0.19	0.51	0.10	0.38	0.21	0.56	0.11
λ_s	0.85	0.79	0.92	0.04	0.92	0.88	0.96	0.03
ρ_{A_x}	0.82	0.68	0.97	0.09	0.91	0.84	0.99	0.05
ρ_A	0.74	0.70	0.79	0.03	0.73	0.69	0.76	0.02
ϕ_π	1.94	1.82	2.06	0.07	2.00	1.89	2.11	0.07
$\sigma^{\varepsilon_{RR}}$	0.05	0.02	0.08	0.02	0.03	0.01	0.04	0.01
$\sigma^{\varepsilon_{TOT}}$	0.12	0.10	0.14	0.01	0.12	0.10	0.14	0.01
$\sigma^{\varepsilon_{Ax}}$	0.01	0.00	0.02	0.01	0.02	0.01	0.03	0.00
$\sigma^{\varepsilon_{YY}}$	0.02	0.01	0.02	0.00	0.02	0.01	0.02	0.00
$\sigma^{\varepsilon_{AA}}$	0.08	0.07	0.10	0.01	0.09	0.07	0.10	0.01
$\sigma^{\varepsilon_{INV}}$	0.12	0.10	0.15	0.01	0.13	0.10	0.15	0.01
$\sigma^{\varepsilon_{CC}}$	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00
$\sigma^{\varepsilon_{YY_x}}$	0.03	0.03	0.04	0.00	0.04	0.03	0.04	0.00

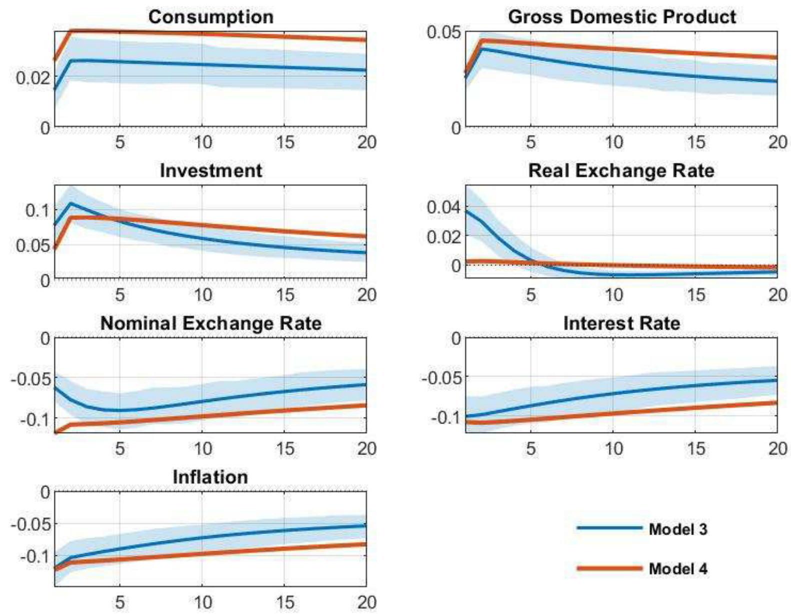


(a) Pre-IT Period: 1997Q1-2003Q4



(b) IT Period: 2004Q1-2017Q4

Figure 1: Identification Strength



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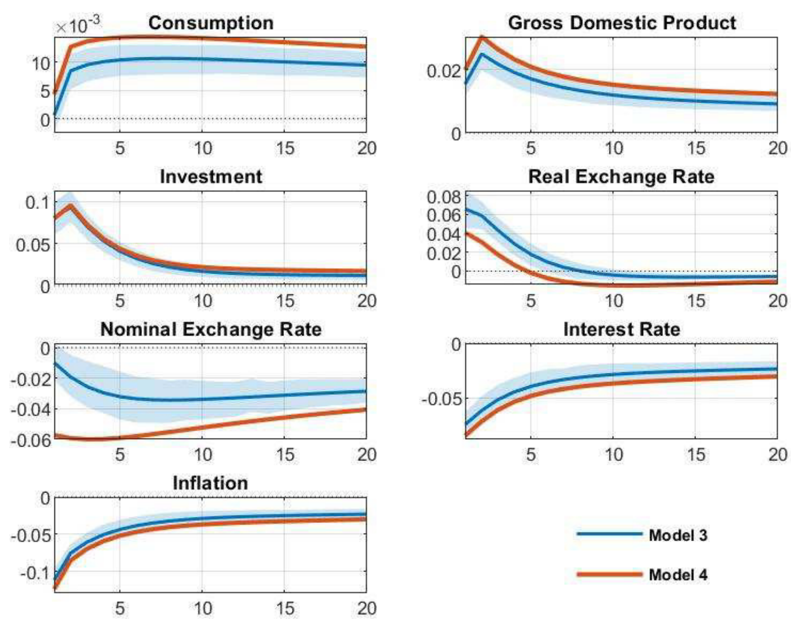
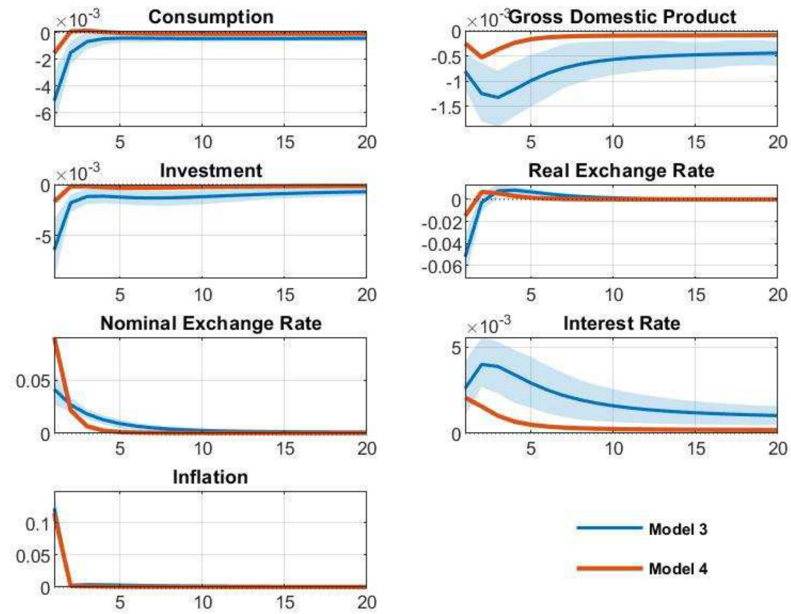


(b) IT Period: 2004Q1-2017Q4

Figure 2: Impulse Response Functions: Manufactuing Sector Productivity Shock. Blue and Orange shaded regions indicate the 90% HPD interval of Model 3 and 4, respectively.



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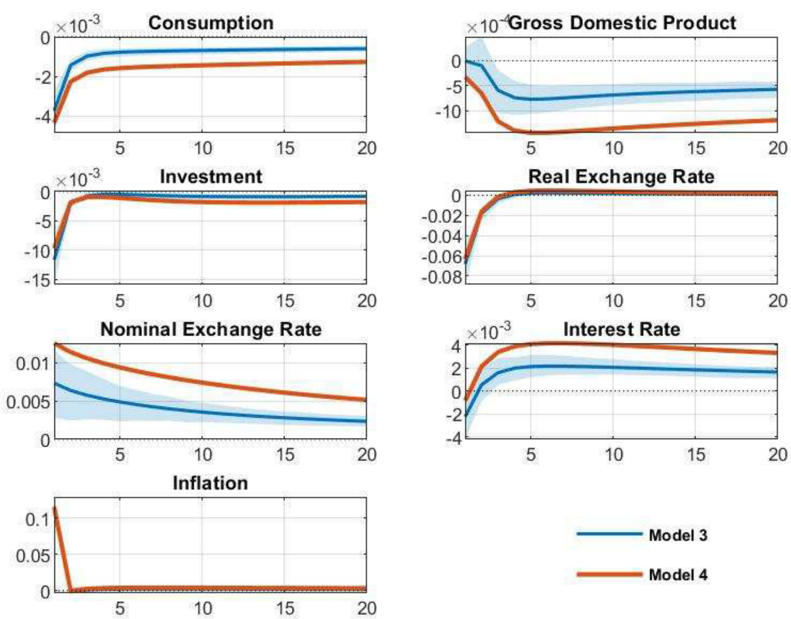
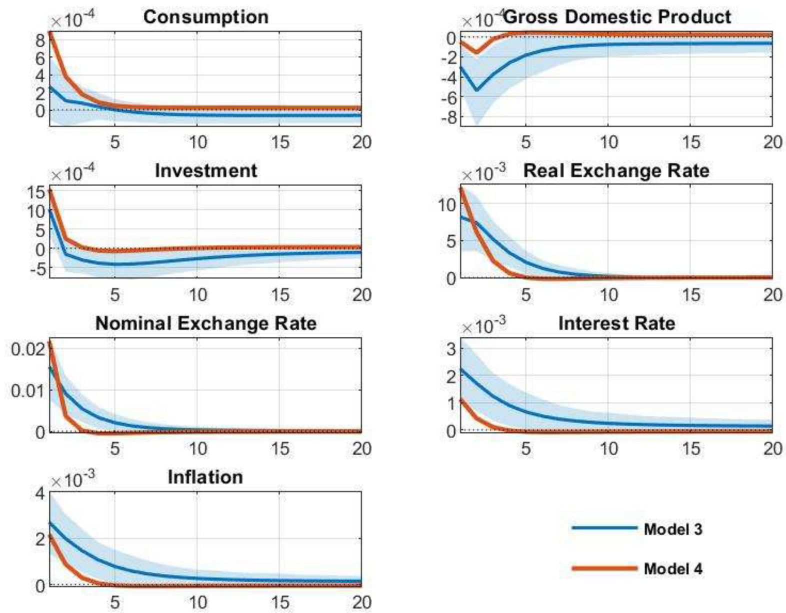
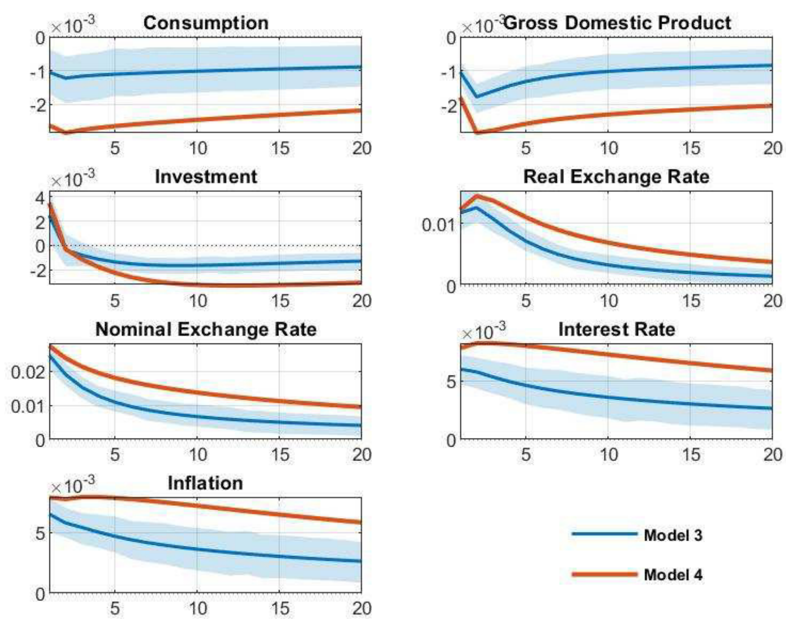


(b) IT Period: 2004Q1-2017Q4

Figure 3: Impulse Response Functions: Cost-Push Shock. Blue and Orange shaded regions indicate the 90% HPD interval of Model 3 and 4, respectively.

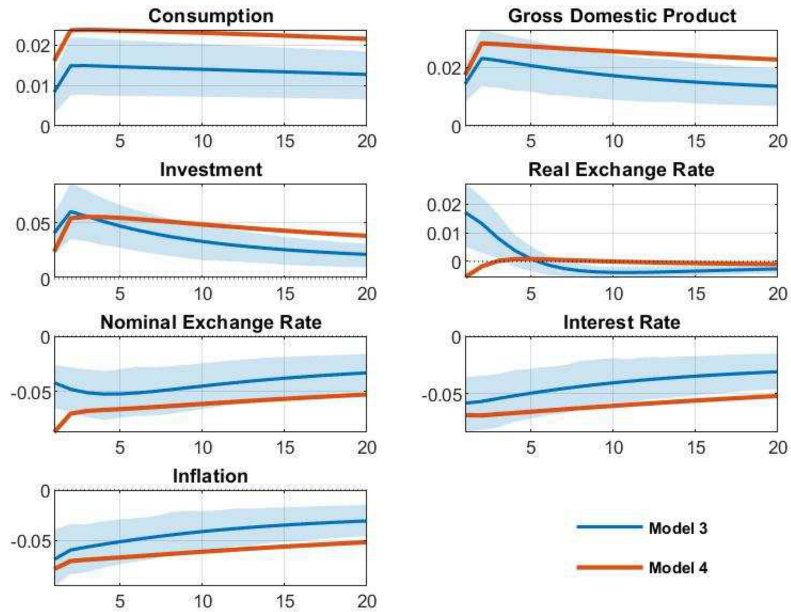


(a) Pre-IT Period: 1997Q1-2003Q4

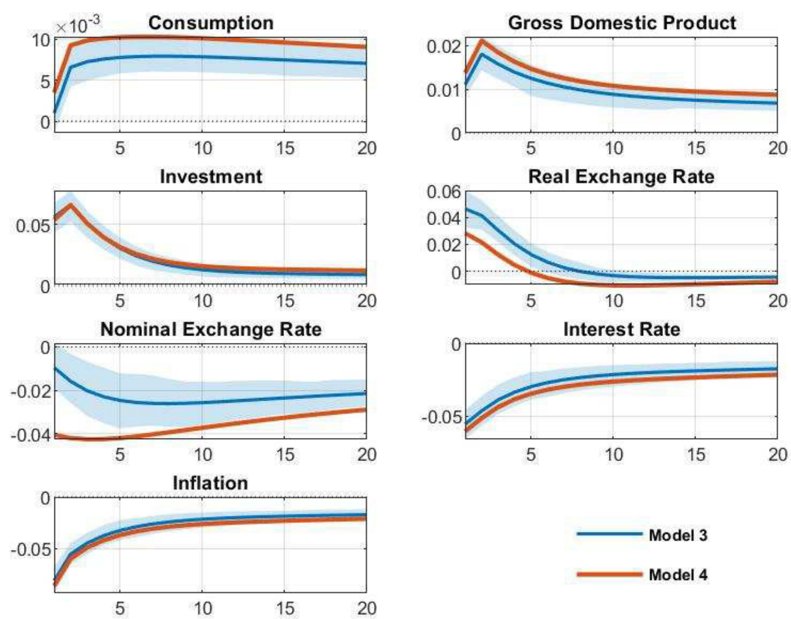


(b) IT Period: 2004Q1-2017Q4

Figure 4: Impulse Response Functions: Risk Premium Shock. Blue and Orange shaded regions indicate the 90% HPD interval of Model 3 and 4, respectively.

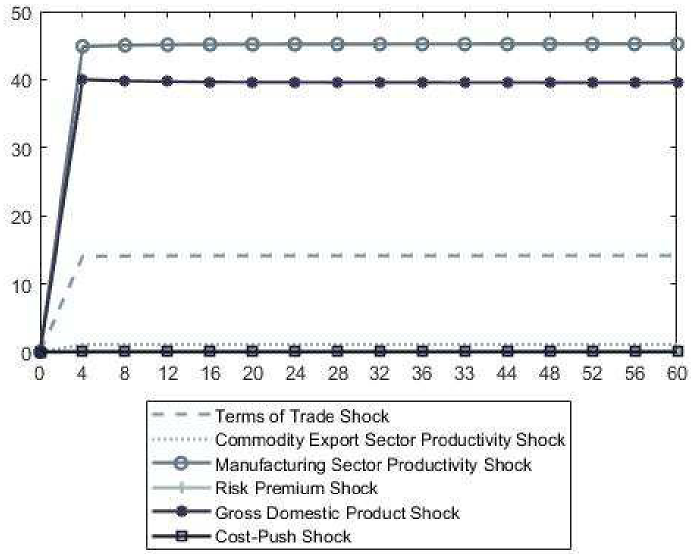


(a) Pre-IT Period: 1997Q1-2003Q4

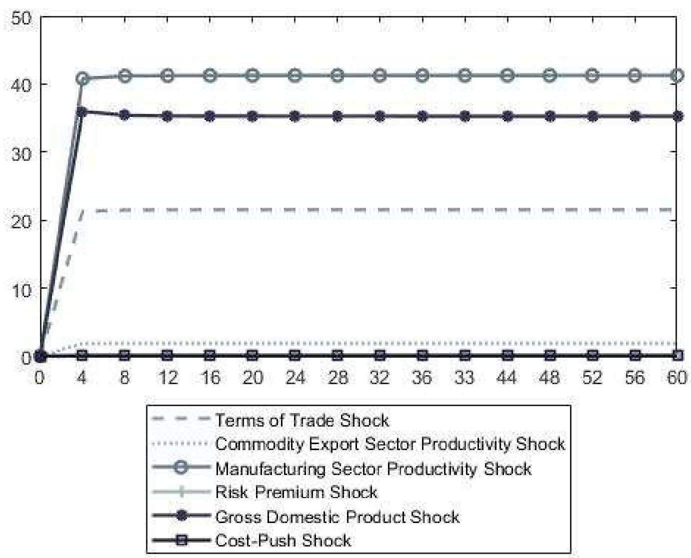


(b) IT Period: 2004Q1-2017Q4

Figure 5: Impulse Response Functions: Terms of Trade Shock. Blue and Orange shaded regions indicate the 90% HPD interval of Model 3 and 4, respectively.

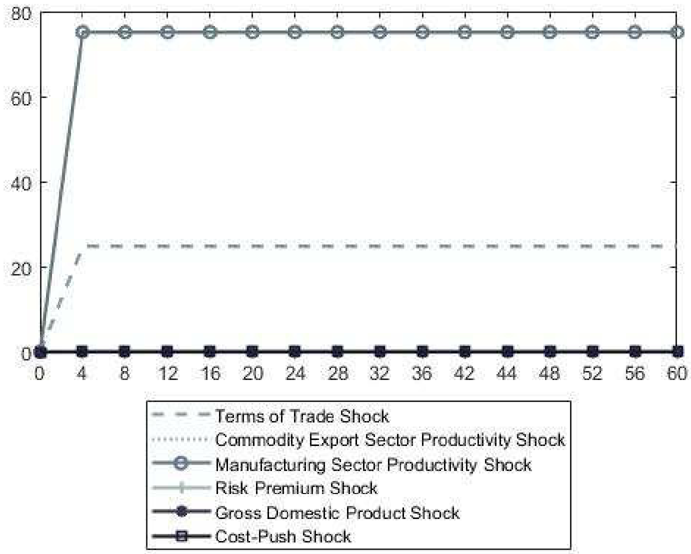


(a) Pre-IT Period: 1997Q1-2003Q4



(b) IT Period: 2004Q1-2017Q4

Figure 6: Forecast Error Variance Decomposition for GDP



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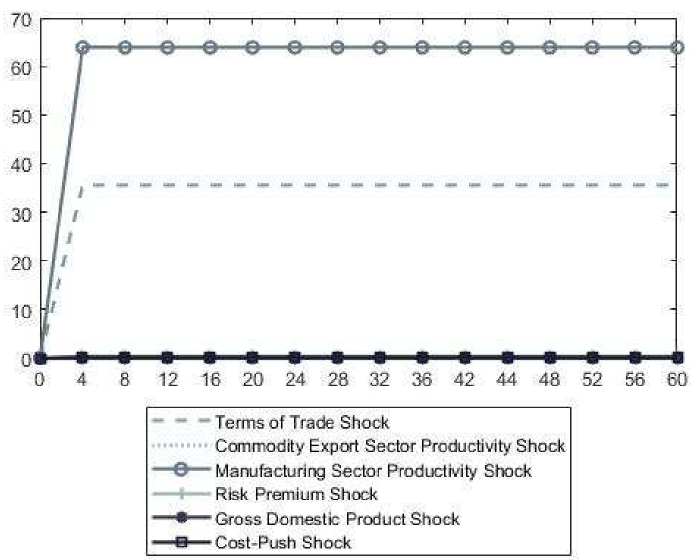

(b) IT Period: 2004Q1-2017Q4

Figure 7: Forecast Error Variance Decomposition for Interest Rate

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