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Foreign Exchange Intervention under Policy Uncertainty

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Abstract

We study the use of foreign exchange (FX) intervention as an additional policy instrument in an environment with learning, where agents infer the central bank policy rules from its policy actions. Under full information, a central bank focused on stabilizing output and inflation can achieve better outcomes by using FX intervention as an additional policy tool. Under policy uncertainty, where agents perceive that monetary policy may also have exchange rate stabilization goals, the use of FX intervention entails a trade-off, reducing output volatility while increasing inflation volatility. While having an additional policy tool is always beneficial, we find that the optimal magnitude of intervention is higher in monetary policy regimes with lower uncertainty. These results indicate that the benefits of using FX intervention as an additional stabilization tool are greater in regimes where monetary policy is credibly focused on output and inflation stabilization.

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I. Introduction

Over the last decade, many emerging market economies relied extensively on foreign exchange (FX) intervention as a macroeconomic policy instrument to cope with capital flow movements (see Figure 1).[1,2] Confronted with sizable capital inflows, many countries faced a dilemma between raising interest rates to contain the expansionary effects of cheap external financing on aggregate demand and inflation, and lowering rates to mitigate the impact of appreciating exchange rates on output. FX intervention and capital controls arose as additional policy instruments to cope with these trade-offs. However, some policy makers and academics questioned whether the use of these additional tools was desirable or even effective in the context of the trilemma of international macroeconomics.[3,4] This controversy triggered new research focused on the role of FX intervention as a macroeconomic stabilization instrument.[5] Ostry et al. (2015), for example, showed that FX intervention can be a useful additional instrument when central banks have, in addition to output and inflation objectives, an exchange rate objective. In a New Keynesian setting, Cavallino (2015) also showed that there is a rationale for using FX intervention when capital inflow shocks lead to inefficient economic fluctuations.[6] While this strand of work made a strong case on the use of FX intervention as an additional policy instrument, the analysis implicitly assumed that policy objectives are known by the public, thus leaving aside informational frictions that may alter the effects of FX intervention, and are paramount in many emerging and developing countries (Boz et al., 2011).

[FIGURE 1]

[1]For a detailed account of policy responses to capital flow shocks, see for example Blanchard et al (2015); IMF (2007, 2010a, 2010b and 2011), and Pradhan et al (2011).

[2]See also a broader discussion on precautionary and mercantilistic motives of FX intervention in Aizenman and Lee (2008), Gagnon (2012 and 2013), Jeanne and Ranciere (2011), Ghosh et al (2012), and Reinhart and Reinhart (2008).

[3]See, for example, Bordo et al. (2012).

[4]According to the trilemma (Obstfeld et al., 2005) policymakers can choose only two of the tree options: stable exchange rates, free capital mobility, and monetary policy independence.

[5]See Benes et al. (2015), Canzoneri and Cumby (2014), and Ostry et al. (2015).

[6]Other related studies on capital flows management include Jeanne and Korinek (2010); Jeanne (2013), Qureshi et al (2011), Ostry et al (2011), and Ostry et al (2010). See also, Benes et al. (2015), Canzoneri and Cumby (2014), and Liu and Spiegel (2015)

In this paper we shed light on the issue of the benefits of using FX intervention when markets perceive that the central bank may an exchange rate objective (in addition to output and inflation objectives). Specifically, we explore the macroeconomic implications of using FX intervention when agents can only infer central bank policy rules by observing its policy actions. To this end, we develop a small open economy with sticky prices à la Calvo (1983) and real wage rigidities as in Shimer (2012). The combination of price and wage rigidities generates a trade-off between output and inflation stabilization (Galí and Blanchard, 2007), and hence the need for a second instrument besides the interest rate policy rule. The model features imperfect substitutability between domestic and foreign assets as in Chang et al. (2015), allowing FX intervention to have real effects. Finally, we also introduce imperfect information and learning about central bank policy objectives. This is a key feature of the model, that allows us to explore the implications of using multiple instruments when agents can only learn gradually about the underlying goals of the central bank.

We analyze the effects of FX intervention for the cases of *full information* (i.e. policy certainty) and *policy uncertainty*. Under full information, central bank policy rules are known to the public. Under policy uncertainty, private agents are uncertain about the central bank they face, which could be of two types: (i) type I conducts monetary policy to achieve output and inflation stability; (ii) type II has an additional exchange rate stabilization goal. Agents have prior beliefs about the central bank policy rules, and update them as they observe policy actions according to an optimal Kalman filtering process as in Erceg and Levin (2003).[7] Observed policy actions may reflect systematic responses (rules) or transitory discretionary deviations from the rule. As agents are unable to disentangle these two drivers from any single policy action, they learn only gradually about the true targets of the central bank, and over time the economy converges to the full information case.[8]

Our analysis focuses on the policy response to a capital inflow episode, modeled as a decline in the foreign interest rate. This shock is not only empirical relevance, but also provides us with an useful illustrative case of inflation and output moving in opposite directions.

We find that under full information the use of FX intervention as a second

[7] See also related work by Schorfheide (2005) and Fuhrer and Hooker (1993).

[8] Our setting can be interpreted as one in which the central bank announces a rule but may deviate from it; or one where agents do not know what the rule is. For this reason, we refer to 'imperfect credibility' and 'policy uncertainty' indistinctly throughout the paper.

policy instrument unambiguously leads to superior macroeconomic outcomes, reducing both output and inflation volatility.

Under policy uncertainty, however, FX intervention entails a trade-off between stabilizing output and inflation. By depreciating the domestic currency, FX intervention stimulates net exports and insulates output from capital inflows. However, the depreciation also entails inflationary pressures. Private agents do not know with certainty whether they face a central bank type I that will raise interest rates to fight the inflationary pressures or a central bank type II that will keep interest rates low in order to avoid an appreciation of its currency. The result of the learning process is greater inflation volatility than under full information, for a given level of intervention. Moreover, we find that the optimal degree of intervention for a central bank focused on stabilizing inflation and output is decreasing in the degree of monetary policy uncertainty.

We also extend the model to study the case of uncertainty about the FX policy rule (i.e., when intervention is perceived to target the exchange rate rather than support monetary policy in its inflation/output objectives). In this case, we also find that output and inflation volatility are higher than in the case of full-information. However, the use of FX intervention remains beneficial as long as monetary policy is credibly anchored on output and inflation stabilization. This is because a credible monetary policy rule can largely offset the excess macroeconomic volatility generated by misperceptions about the FX intervention rule.

Overall, our results suggest that the benefits of using FX intervention as an additional macroeconomic stabilization tool are increasing in the degree of monetary policy certainty. That is, FX intervention is more effective under regimes where monetary policy is focused on stabilizing inflation and output. Moreover, whether FX intervention is perceived to support output and inflation stability goals, or to be aimed at achieving an additional target, appears to be of second order importance provided that monetary policy is credibly geared towards output and inflation stabilization.

The remainder of the paper is organized as follows. Section II lays out the small open economy model and describes the calibration strategy. Section III discusses the simulations results under full information and policy uncertainty. Section IV concludes with the key takeaways.

II. A Two-sector Small Open Economy Model

We develop a small open economy model featuring nominal and real rigidities along the lines of Christiano et al. (2005), Smets and Wouters (2007), Adolfson et al. (2008), Altig et al. (2011). There are two sectors in the economy: one producing a tradable good (T) and the other a non-tradable good (N). We assume sticky prices in the non-tradable sector whereas the law of one price holds for the tradable goods. We introduce real wage rigidities as in Blanchard and Galí (2009) and Shimer (2012). Finally, domestic and foreign bonds are assumed to be imperfect substitutes as in Chang et al. (2015), allowing for FX intervention to be an additional macroeconomic stabilization tool.

A. Households

Household's preference are defined over consumption and labor as:

$$U_t = E_t \left[\sum_{i=0}^{\infty} \beta^i u(C_{t+i}, L_{t+i}) \right], \tag{1}$$

where L_t denotes labor effort and C_t consumption. Households have access to two types of assets: non-contingent foreign and domestic bonds, B_t^* and B_t. Their budget constraint is given by:

$$\begin{aligned} P_t^F C_t + B_t + \mathcal{E}_t B_t^* &= B_{t-1}\left(1+i_{t-1}\right) + \mathcal{E}_t B_{t-1}^* \left(1+i_{t-1}^*\right) \Theta\left(\overline{B}_{t-1}^*\right) \\ &\quad + W_t l_t + \Pi_t + T_t, \end{aligned} \tag{2}$$

where P_t^F is the price of final goods, i_t is the domestic interest rate, $\mathcal{E}_t$ is the nominal exchange rate, W_t is the nominal wage, Π_t are profits generated by firms, and T_t are lump-sum transfers from the central bank. The return on foreign bonds is given by the foreign interest rate i_t^* and a risk premium $\Theta(\overline{B}_{t-1}^*)$. This premium, standard in small open economy models, is a function of the aggregate stock of foreign debt $\overline{B}_{t-1}^*$.[9] The endogenous risk premium generates imperfect asset substitutability between domestic

[9] In this set up, as in Schmitt-Grohé and Uribe (2003), the representative household does not internalize the effects of borrowing on the risk premium.

and foreign bonds, and allows FX intervention to have real effects in the economy. [10]

B. Real Wage Rigidities

Real wages are rigid as in Blanchard and Galí (2009) and Shimer (2012), and are assumed to evolve according to the following adjustment process:

$$\frac{W_t}{P_t^F} = \left(\frac{W_{t-1}}{P_{t-1}^F}\right)^{\chi_w} (w_t^*)^{1-\chi_w}, \tag{3}$$

where the parameter $\chi_w \in [0,1]$ determines the degree of inertia in real wages and $w_t^* = -\frac{u_{L,t}}{u_{C,t}}$ is the target real wage determined by the household's marginal rate of substitution between consumption and leisure. Equation (3) states that the real wage gradually adjusts to the target real wage, which corresponds to the equilibrium under flexible wages. Similarly, $\chi_w = 0$ corresponds to the case of fully flexible wages.

C. Firms

There are four types of firms in the economy: final good producers, intermediate good producers, retailers and capital producers. Next, we describe the structure of these firms.

1. Final good producers

Producers of final goods (Y_t^F) combine tradable intermediate input (Y_t^{DT}) and non-tradable intermediate input (Y_t^{DN}) according to a constant elasticity of substitution function:

$$Y_t^F = \left[\alpha_Y^{1/\eta_Y} (Y_t^{DT})^{\frac{\eta_Y-1}{\eta_Y}} + (1-\alpha_Y)^{1/\eta_Y} (Y_t^{DN})^{\frac{\eta_Y-1}{\eta_Y}}\right]^{\frac{\eta_Y}{\eta_Y-1}}, \tag{4}$$

where α_Y and η_Y are the share of tradable inputs and the elasticity of substitution between tradable and non-tradable inputs, respectively. The price of the final good is given by:

$$P_t^F = \left[\alpha_Y \left(P_t^T\right)^{1-\eta_Y} + (1-\alpha_Y)\left(P_t^N\right)^{1-\eta_Y}\right]^{\frac{1}{1-\eta_Y}}, \tag{5}$$

[10] See similar specifications in Schmitt-Grohé and Uribe (2003) and Chang et al. (2015).

where P_t^T and P_t^N are the price of tradable and non-tradable inputs, respectively

2. Intermediate Good Producers

Firms produce intermediate tradable and non-tradable goods denoted by Y_t^T and Y_t^N, respectively, in a competitive market. The production function in each sector $J = T, N$, is given by:

$$Y_t^J = A_t^J \left[K_t^J\right]^{\eta_J} \left[L_t^J\right]^{1-\eta_J}, \tag{6}$$

where A_t^J, K_t^J, and L_t^J, denote aggregate productivity, capital and labor inputs in each sector, respectively.

3. Retailers in the Non-Tradable Sector

Firms in the retail sector sell non-tradable goods (Y_t^{DN}) in two separate stages. First, there is an assembler that combines the differentiated intermediate non-tradable goods indexed by $j \in [0,1]$ to produce Y_t^{DN}. The technology is a constant elasticity of substitution function given by:

$$Y_t^{DN} = \left(\int_0^1 Y_t^{DN}(j)^{\frac{\epsilon_N - 1}{\epsilon_N}} dj\right)^{\frac{\epsilon_N}{\epsilon_N - 1}}, \tag{7}$$

where ϵ_N is the elasticity of substitution between a variety of goods. The resulting demand for the jth intermediate non-tradable good is:

$$Y_t^{DN}(j) = \left(\frac{P_t^N(j)}{P_t^N}\right)^{-\epsilon_N} Y_t^{DN}. \tag{8}$$

From the zero-profit condition for the assembler we obtain the aggregate price of non-tradable goods:

$$P_t^N = \left(\int_0^1 P_t^N(j)^{1-\epsilon_N} dj\right)^{\frac{1}{1-\epsilon_N}}. \tag{9}$$

Second, retailers purchase the homogenous intermediate good and differentiate it into a continuum of goods. Each retailer sets their prices on a staggered basis as in Calvo (1983). Every period a fraction $(1 - \theta_N)$ of retailers set their prices optimally while the remaining fraction are not able to change prices. The optimal price P_t^{N*} chosen by each retailer maximizes the expected present value of profits:

$$E_t \left[\sum_{i=0}^{\infty} (\theta_N)^i \Lambda_{t,t+i} \left(P_t^{N*} - P_{t+i}^{WN} \right) Y_{t+i}^N(j) \right], \tag{10}$$

where $\Lambda_{t,t+i}$ is the stochastic discount factor defined as $\Lambda_{t,t+i} = \beta^i (C_t / C_{t+i})(P_t^F / P_{t+i}^F)$ and P_t^{WN} is the wholesale price of the intermediate good of the non-tradable sector determined competitively in the intermediate goods market. The aggregate price of non-tradable goods evolves according to:

$$P_t^N = \left[\theta \left(P_{t-1}^N \right)^{1-\varepsilon_p} + (1-\theta) \left(P_t^{N*} \right)^{1-\varepsilon_p} \right]^{\frac{1}{1-\varepsilon_p}}. \tag{11}$$

4. Capital producers

Capital is sector-specific and there are firms designated to produce and rent capital to the intermediate good producers in the tradable and non-tradable goods sector. The aggregate investment goods of each type of capital is a composite of tradable and non-tradable goods as in the case of the final good. The representative firm producing for a sector $J = \{T, N\}$ solves the following problem:

$$V_t^J = \max_{K_{t+i}^J, I_{t+i}^J} E_t \left\{ \sum_{i=0}^{\infty} \Lambda_{t,t+i} (R_{K,t+i}^J K_{t+i}^J - P_{t+i}^F I_{t+i}^J) \right\},$$

subject to the law of motion of physical capital:

$$K_{t+1}^J = (1-\delta) K_t^J + S\left(\frac{I_t^J}{I_{t-1}^J} \right) I_t^J, \tag{12}$$

where V_t^J the present discounted value of profits, δ is the depreciation rate of capital in sector J. $S(.)$ characterizes the adjustment cost for investment.[11]

[11] Investment adjustment costs, as in Christiano et al. (2005), satisfy the following conditions: $S(1) = 1$, $S'(1) = 0$, $S''(1) = -\mu_S < 0$. This assumption generates inertia in investment that is consistent with a time-to-build specification.

D. Monetary and Foreign Exchange Reserves Policies

The central bank's budget constraint is given by:

$$\mathcal{E}_t F_t^* - B_t = \mathcal{E}_t F_{t-1}^*(1 + i_{t-1}^*) - B_{t-1}\,(1 + i_{t-1}) - T_t, \qquad (13)$$

where F_t^* is the stock of foreign exchange reserves. Sterilized FX intervention is conducted by issuing ΔB_t units of domestic bonds and purchasing $\mathcal{E}_t \Delta F_t^*$ units of risk-free foreign assets ($\mathcal{E}_t \Delta F_t^* = \Delta B$). Each period the central bank earns interest income $\mathcal{E}_t F_{t-1}^*(1+i_{t-1}^*)$ on the stock of reserves of the previous period, and pays $B_{t-1}\,(1 + i_{t-1})$ to domestic bond holders. Profits or losses are rebated to the households through lump-sum transfers T_t.

Central bank policies are modeled as rules for the short-term interest rate, i_t and the stock of foreign exchange reserves, F_t^*. Below we analyze alternative regimes defined by the degree of credibility of these macroeconomic policy rules. Our focus is on a central bank (which we call type 1) that sets the interest rate according to a Taylor-type rule:

$$\left(\frac{1+i_t}{1+i}\right) = \left(\frac{1+i_{t-1}}{1+i}\right)^{\psi_i} \left(\frac{Y_t}{\overline{Y}}\right)^{(1-\psi_i)\psi_y} \left(\frac{\pi_t}{\overline{\pi}}\right)^{(1-\psi_i)\psi_\pi} exp(\varepsilon_{mp,t}), \qquad (14)$$

where i_t, Y_t, π_t are the nominal interest rate, output, and the inflation rate, respectively. The parameter ψ_i indicates the degree of interest rate smoothing in the Taylor-type rule, and ψ_y and ψ_π denote the weights for output and inflation stabilization. The last term, $\varepsilon_{mp,t}$, is an i.i.d. shock, with mean 0 and standard deviation σ_{mp}^2, that reflects transitory deviations of the interest rate from the policy rule.

The foreign exchange intervention policy is characterized by a rule of reserve accumulation as a function of the foreign interest rate:[12]

$$\frac{F_t^*}{\overline{F}^*} = \left(\frac{1+i_t^*}{1+\overline{i^*}}\right)^{-\theta_{i^*}} exp(\varepsilon_{fx,t}), \qquad (15)$$

where the intensity of FX intervention is governed by the parameter θ_{i^*}; $\overline{F}^*$ and $\overline{i^*}$ are the steady state values for the foreign exchange reserves and the foreign interest rate, respectively; and $\varepsilon_{fx,t}$, is an i.i.d. shock with mean 0 and standard deviation σ_{fx}^2.

[12] Since the simulations are only focused on foreign interest rate disturbances, different specifications of the FX reserves rule give quantitatively similar rules to the specification in equation (15).

E. Market Clearing Conditions

In each period, markets for labor, capital, domestic and international bonds, intermediate and final goods clear. The market clearing condition for labor is given by:

$$L_t = L_t^N + L_t^T, \tag{16}$$

The market clearing condition for non-tradable goods is:

$$Y_t^{DN} \Xi_t^N = Y_t^N, \tag{17}$$

where Ξ_t^N captures a term of price dispersion of retailers in the non-tradable sector.

The aggregate domestic demand for final goods satisfies:

$$Y_t^F = C_t + I_t^T + I_t^N. \tag{18}$$

The law of one price holds for tradable goods, implying:

$$P_t^T = \mathcal{E}_t P_t^*. \tag{19}$$

where P_t^* is the price of the tradable goods in foreign currency.

In equilibrium, $\overline{B}_t^* = B_t^*$. Combining the households and government budget constraints, we obtain the balance of payment identity:

$$\begin{aligned} \mathcal{E}_t(B_t^* + F_t^*) &= (1 + i_{t-1}^*) \left(\Theta \left(B_{t-1}^* \right) \mathcal{E}_t B_{t-1}^* + \mathcal{E}_t F_{t-1}^* \right) + P_t^T Y_t^T \\ &\quad - P_t^T Y_t^{DT}. \end{aligned} \tag{20}$$

F. Calibration

The model is calibrated at a quarterly frequency for a prototypical small open economy. Consistent with an annual real interest rate of 4 percent, we set $\beta = 0.99$. Household preferences are represented by the functional form:

$$u(C_t, L_t) = \log(C_t) - \varphi \frac{(L_t)^{1+\nu}}{1+\nu}, \tag{21}$$

where the inverse of the Frisch elasticity of the labor supply is set to $\nu = 5/3$. The share of tradable goods in the final goods basket is 50 percent ($\alpha_Y = 0.5$) whereas the elasticity of substitution between tradable and non-tradable goods is $\eta_Y = 0.5$. The elasticity of substitution among differentiated intermediate non-tradable goods is such the average markup in that sector is 20 percent ($\epsilon_N = 6$). Consistent with standard New-Keynesian models, we set the frequency of price adjustment to four quarters ($\theta_N = 0.75$). Real wage rigidities are set to $\chi_w = 0.875$, which is consistent approximately with a half-life duration of wage adjustment of 5 quarters. The elasticity of the investment adjustment cost is $\mu_S = 2.5$ consistent with the values from Christiano et al. (2005).

The risk premium elasticity of the foreign debt ($\varrho = (\Theta'/\Theta)B^*$) is calibrated according to empirical evidence, from Bayoumi et al. (2015), on the effect of FX intervention on the current account balance. The only source of fluctuations considered in the model is the foreign interest rate, which follows an AR(1) process with persistence $\rho_{i^*} = 0.95$.

The interest rate rule is calibrated with standard parameter values ($\psi_\pi = 1.5$, and $\psi_y = 0.5$); while the elasticity of FX reserves to the foreign interest rate θ_{i^*} is chosen to minimize a loss function based on output and inflation volatility, $L = var(y_t) + var(\pi_t)$.[13] Table 1 summarizes the parameter values for the baseline calibration.

[13] We also computed the optimal value of θ_{i^*} based on maximizing the household's welfare and the quantitative implications of the the optimal FX intervention rule are similar.

Table 1: Baseline Calibration

Parameter	Value	Description
β	0.99	Discount Factor
$1/\nu$	0.60	Labor Supply Elasticity
α_Y	0.50	Share of Tradable Inputs - Final Good Sector
η_Y	0.50	Elasticity of Substitution - Final Good Sector
ε_N	6	Elasticity of Substitution - Non-tradable Sector
θ_N	0.75	Calvo Parameter - Non-tradable Sector
χ_w	0.875	Wage rigidity parameter
η_N	0.30	Capital Share - Non-tradable Sector
η_T	0.40	Capital Share - Tradable Goods Sector
δ	0.02	Depreciation Rate
μ_S	2.5	Investment adjustment cost
ψ_i	0.7	Interest Rate Smoothing Coefficient - Taylor Rule
ψ_π	1.5	Inflation Coefficient - Taylor Rule
ψ_y	0.5	Output Coefficient - Taylor Rule
ψ_{i^*}	1	Foreign Interest Rate Coefficient - Taylor Rule
θ_{i^*}	9.7	Foreign Interest Rate Coefficient - FXI Rule
ϱ	0.2	Foreign risk premium elasticity
ρ_{i^*}	0.95	Persistence of foreign interest rate

III. Capital Inflows and FX intervention

Our analysis focuses on the implications of FX intervention in response to a capital inflow shock, modeled as a 1 percent drop in the foreign interest rate (i^*). We analyze the implications of using FX intervention as a second instrument for the cases of full information and policy uncertainty.

A. Full Information

The case of full information follows directly from the previous description of the model, where central bank type 1 is the only type. Monetary policy is conducted according to equation (14) and, when used, and FX intervention is conducted according to equation (15). Figure 2 displays the impulse response functions, both for the cases of one instrument (monetary policy), and two instruments (monetary and FX intervention policy).

[FIGURE 2]

In the case of one instrument (i.e., setting $\theta_{i^*} = 0$), the drop in the foreign interest rate leads to a nominal exchange rate appreciation that reduces headline inflation and generates a reallocation of resources from the tradable to the non-tradable sector.[14,15] The latter leads to a short-lived boost in GDP followed by a contraction as tradable production responds to the exchange rate appreciation.[16] While the policy rate falls in response to the shock, monetary policy is insufficient to stabilize output and inflation. The central bank faces a trade-off between stabilizing output and stabilizing inflation, as these two variables move in opposite directions.

Consider now the case of two instruments, where the central bank conducts FX intervention in a way that supports monetary policy. That is, the parameter θ_{i^*} is chosen optimally in order to minimize the sum of output and inflation volatility. As shown by the blue line, the second instrument (FX reserves) has powerful stabilization properties. An accumulation of FX reserves in response to capital inflows engineers a real exchange rate depreciation, boosting tradable output, the current account and inflation, relative to the case of one instrument. Consistent with the Tinbergen principle, the use of two instruments allows to achieve two targets, namely output and inflation stabilization, unambiguously improving macroeconomic outcomes relative to the case of one instrument. See also Figure 5, which depicts the macroeconomic outcomes in terms of the policy objectives of central bank type 1 (i.e., inflation and output volatility).

B. Policy Uncertainty

Consider now the case of policy uncertainty, under which private agents are uncertain about the monetary policy rule implemented by the central bank in response to the capital inflow shock. Our focus is on central banks type 1, but we study the case when agents are uncertain about whether they face a central bank type 1, which follows a Taylor rule as in equation (14); or a central bank type 2, which exhibits "fear of floating" and moves the

[14] There is also a transitory decline in the current account balance as a result of a drop in tradable goods production and higher imports.

[15] As shwon in Figure 2b, the ratio of reserves-to-GDP moves somewhat, simply reflecting variations in the denominator.

[16] These responses are consistent with recent empirical evidence. See, for example, IMF (2014 and 2015), and Blanchard et al (2015).

domestic policy rate in response to changes in the foreign interest rate in order to mitigate the impact on the nominal exchange rate, according to the following rule:

$$\left(\frac{1+i_t}{1+i}\right) = \left(\frac{1+i_{t-1}}{1+i}\right)^{\psi_i} \left[\left(\frac{Y_t}{\overline{\overline{Y}}}\right)^{\psi_y} \left(\frac{\pi_t}{\overline{\pi}}\right)^{\psi_\pi} \left(\frac{1+i_t^*}{1+i^*}\right)^{\psi_{i^*}}\right]^{(1-\psi_i)} exp(\varepsilon_{mp,t}), \tag{22}$$

where the coefficient on the foreign interest rate ψ_{i^*} is set to 1 based on the empirical evidence from Caputo and Herrera (2013). This rule is consistent with the notion of fear of floating stressed by Calvo and Reinhart (2002), and the evidence presented by Vegh and Vuletin (2012) who argue that the inability of having a countercyclical monetary policy in many emerging economies is related to the need to defend the value of their currency ("fear of free falling").[17] In our setting, this means that a central bank type 2 will tend to resist the appreciation stemming from the capital inflow shock by moving its interest rate in tandem with the foreign interest rate, thus deviating from the standard (type 1) Taylor-type rule described in equation (14).[18]

Learning impedes private agents from immediately inferring the rule being implemented by the central bank. Formally, this means that the log deviation of the interest rate rule, which can be written as:

$$\begin{aligned} dev_{mp,t} &= \ln\left(\tfrac{1+i_t}{1+i}\right) - \psi_i \ln\left(\tfrac{1+i_{t-1}}{1+i}\right) \\ &\quad -(1-\psi_i)\left(\psi_y \ln\left(\tfrac{Y_t}{\overline{\overline{Y}}}\right) + \psi_\pi \ln\left(\tfrac{\pi_t}{\overline{\overline{\pi}}}\right)\right) \end{aligned} \tag{23}$$

provides an imperfect signal about the systematic behavior of the monetary policy rate. Observed deviations can be due to a monetary policy shock ($\varepsilon_{mp,t}$) or to the fact that the central bank is of type 2. Market participants assign probabilities to each type ($pr_{1,t}$ and $pr_{2,t}$,) in order to forecast the expected path of the short-term interest rate; and use Bayesian inference to

[17] Empirically there is a strong association between the domestic policy rate in small open economies and foreing interest rates. Taylor (2014) argues that this correlation reflects the concern of the central banks for the value of the exchange rate. For empirical estimates on the impact of foreign interest rates on policy rates see Clarida, Galí and Gertler (1998), Rey (2015), Caputo and Herrera (2013) and Gray (2013).

[18] In this setting, the 'fear of floating' of central bank type 2 is suboptimal (from the perspective of stabilizing output and inflation); but it can be rationalized, for example, by introducing balance sheet effects.

update their beliefs about these probabilities and the policy shock.[19] The prior probability of being type 1 is calibrated to 50 percent ($pr_{1,0|0} = 0.5$), and we later conduct sensitivity analysis on this parameter. For the implementation of the Bayesian inference, the vector of states is defined as:

$$\xi_t = \begin{bmatrix} pr_{1,t} & pr_{2,t} & \varepsilon_{mp,t} \end{bmatrix}' \tag{24}$$

Upon observing $dev_{mp,t}$, private agents infer the vector ξ_t using the Kalman Filter:

$$\xi_{t|t} = \begin{bmatrix} pr_{1,t|t} & pr_{2,t|t} & \varepsilon_{mp,t|t} \end{bmatrix}' \tag{25}$$

where $pr_{j,t|t}$ corresponds to the probability of the central banks being of type j in period t, based on the information available up to t; and $\varepsilon_{mp,t|t}$ is the inferred monetary policy shock based on the same information set.[20]

It is useful to start by comparing the dynamics under perfect and imperfect credibility when only one instrument, i.e. monetary policy, is used (Figure 3). The effect of the capital inflow shock on inflation is more muted under imperfect credibility, reflecting a more limited impact on the nominal exchange rate, while the impact on output is more pronounced. The response of the economy is influenced by private expectations that the central bank may be of type 2 and thus likely to move future policy rates to mitigate the impact of the shock on the nominal exchange rate. Interestingly, the spike in inflation is sufficiently large to induce a hike in nominal interest rates, although the real interest rate still fall more under imperfect credibility.

[FIGURE 3]

The use of FX intervention, in addition to monetary policy, under policy uncertainty helps to mitigate the impact on output but at expense of higher inflation (comparing purple and green lines in Figure 4). Households anticipate a larger depreciation induced by the possibility that the central bank pursues a "fear of floating" monetary policy. The nominal depreciation arising from the use of FX intervention helps to stabilize output, but the

[19] This process is similar to the one proposed by Erceg and Levin (2003) to explain how credibility problems raise the cost of disinflation.

[20] The Kalman filter provides the optimal inference process about the unobservable states (see appendix for a detailed description of the implementation).

associated inflationary effect is amplified as monetary policy lacks credibility to anchor inflation expectations.[21] As opposed to the case of full information, the use of FXI as a second instrument has ambiguous benefits in terms of output and inflation stabilization. That is, FX intervention entails a trade-off between these two objectives.

[FIGURE 4]

Figure 5 summarizes the results in terms of output and inflation volatility. Panel A shows the case of full information. Starting from the case of one instrument (monetary policy) at point A, the use of FX intervention as an additional instrument unambiguously reduces macroeconomic volatility (point B). The outcome is different if monetary policy lacks credibility (Panel B). In that case, adding an instrument (moving from point C to D) implies a trade-off. Although the use of FX reserves is capable of stabilizing output, this is achieved at expense of higher inflation volatility.[22]

[FIGURE 5]

1. Gains from the Second Instrument

Arguably one of the most important parameters in the calibration is the prior probability of being a central bank type 1. Thus, next we examine the implications of different values for this probability. Figure 6 plots the inflation/output outcomes under 1 instrument (orange dots) and 2 instruments (blue dots), for different prior beliefs (panel a). Except for values close to 1 of the probability of being type 1 ($pr_{1,0/0}$), there is a continuous increase in inflation and output volatility as the $pr_{1,0/0}$ falls. This illustrates

[21] Interestingly, the current account dynamics does not change significantly, arguably as a result of the assumption of flexible prices in the tradable sector.

[22] One can measure the cost of policy uncertainty by the distance between points A and C for the case of 1 instrument; and B and D for the case of 2 instruments. Under 1 instrument, uncertainty has ambigous effects (as some degree of response to the foreign interest rate is optimal). In the case of 2 instruments, however, uncertainty has unambiguos negative effects, worsening outcomes in both dimensions.

the cost of policy uncertainty.[23] On the other hand, the gain from using a second instrument (given a certain degree of policy uncertainty) is given by the shift from the orange to the blue line. As apparent in the figure, there is an unambiguous gain from using the second instrument for high credibility cases, but this is not necessarily the case for low credibility cases. Panel b summarizes these outcomes, showing that the benefit of using FX reserves as a second instrument (in terms of the loss function metric of inflation and output volatility) is increasing in the degree of credibility (policy certainty).

[FIGURE 6]

2. Optimal FX Intervention

So far the analysis for the case of uncertainty assumed the central bank followed the same rule that it would optimally implement under certainty. We now explore whether the optimal degree of FX intervention depends on the degree of central bank credibility (i.e., the prior probability of being type 1). Specifically, we focus on the case of uncertainty about the monetary policy rule, now allowing central bank type 1 to optimize the FX intervention rule taking into account the behavior, and the prior probability, of the central bank type 2. As shown in Figure 7, the optimal degree of intervention is increasing in the degree of credibility. This is because the greater credibility implies less inflationary effects of using FX intervention, and thus the instrument can be used to a greater extent to stabilize both output and inflation.

[FIGURE 7]

3. Sensitivity Analysis of Model Parameters

We also conduct sensitivity analysis on four additional key parameters: (ii) the degree of price stickiness (θ_N); (iii) the degree of real wage rigidity (χ_w); (iv) the persistence of the capital inflow shock (ρ_{i^*}); and (v) the degree of asset substitutability (ϱ). The main results hold for a wide range of values, as shown in Appendix Tables A2-A5.

[23] As mentioned before, the non-monotonicity around high values of $pr_{1,0/0}$ reflects that some degree of response to the foreign interest rate (which only central bank type 2 implements, although in excess) is optimal.

C. Exchange Rate Policy Uncertainty

We extent our analysis also to the case of imperfect credibility about the FX intervention rule. In this case, we assume that there is no uncertainty about the conduct of monetary policy but, when used, the conduct of FX intervention is uncertain. This can be interpreted as uncertainty on whether intervention is meant to support monetary policy in its inflation/output stabilization goals, or if the additional instrument is used for a separate objective.

In this case, although the central bank follows a FX intervention rule as in equation (15), private agents believe that FX intervention may be determined by an alternative (central bank type 2) rule of the form:

$$\frac{F_t^*}{\overline{F}^*} = \left(\frac{1+i_t^*}{1+\overline{i}^*}\right)^{-\mu\theta_{i^*}} exp(\varepsilon_{fx,t}) \tag{26}$$

where $\mu > 1$ indicates a desire to depreciate the exchange rate beyond the response dictated by output and inflation stabilization motives. In our benchmark simulation, we calibrate $\mu = 2$ (twice as large as the optimal value under certainty).[24] As before, and as the economy evolves, agents learn about the intervention rule in place, based on the deviations of FX reserves from the announced rule:

$$dev_{fx,t} = \ln\left(\frac{F_t^*}{\overline{F}^*}\right) - \theta_{i^*}\ln\left(\frac{1+i_t^*}{1+\overline{i}^*}\right) \tag{27}$$

The results (Figure 8) indicate that there is little difference between the outcomes under full and low credibility in the benchmark calibration. This is because policy uncertainty is only attached to the FX intervention rule, and monetary policy (still observed with certainty) is able to offset the costs associated with the misperception of the FX intervention rule.

[FIGURE 8]

Moreover, sensitivity analysis on the prior beliefs (Figure 9) indicates that only in very low credibility cases, FX intervention may be counterproductive. This indicates that policy uncertainty about the conduct of FX intervention

[24] This value induces an accumulation of FX reserves of 5 percentage points of GDP, reflecting the "fear of floating" behavior by the type 2 central bank.

(whether is targeted to support monetary policy objectives or other goals) is of second order importance.

[FIGURE 9]

IV. Conclusions

In this paper we studied the macroeconomic implications of FX intervention under full information and policy uncertainty. Under full information, the use of FX intervention as an additional stabilization instrument unambiguously improves macroeconomic outcomes. When there is uncertainty about the goals of monetary policy, however, FX intervention entails a trade-off between stabilizing output and stabilizing inflation. The benefits of using this additional instrument are decreasing in the degree of policy uncertainty, and so is the degree of intervention for a central bank focused on inflation and output (but perceived otherwise).

Finally, uncertainty about the conduct of FX intervention (whether it is aimed at supporting monetary policy goals or at an exchange rate target) appears to be of second order importance provided that monetary policy is credibly focused on stabilizing inflation and output.

Our analysis underscores the importance of credibility of the monetary policy regime in order to maximize the stabilization benefits of using FX intervention as an additional policy instrument.

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Appendix I: Simulation with Learning

In this appendix we describe the simulation under limited credibility, based on the log-linear approximation of the equilibrium conditions of the model. In particular, conditional of being a type j monetary authority, the solution of the model can be written as:

$$\widehat{\mathbf{X}}_t = \mathbf{P}\widehat{\mathbf{X}}_{t-1} + \mathbf{Q}_{i^*,j}\widehat{i}_t^* + \mathbf{Q}_{mp}\varepsilon_{mp,t} \tag{28}$$

where $\widehat{\mathbf{X}}_t$ is a vector containing all endogenous variables (expressed as log deviation from their steady state values), $\widehat{i}_t^*$ is the corresponding log deviation of the foreign interest rate, and $\varepsilon_{mp,t}$ is the monetary policy shock. $\mathbf{P}$, $\mathbf{Q}_{i^*,j}$, and $\mathbf{Q}_{mp}$ are a matrix and two column vectors, respectively, which are functions of the structural parameters of the model.

Using this notation, the dynamics of the model under perfect credibility are characterized by (28) for the case $j = 1$. Under limited credibility, the private sector make inference about the probabilities of the two types of monetary authorities and the size of the monetary policy shock to obtain the dynamic response to a foreign interest rate shock:

$$\widehat{\mathbf{X}}_t = \mathbf{P}\widehat{\mathbf{X}}_{t-1} + \left(pr_{1,t|t}\mathbf{Q}_{i^*,1} + pr_{2,t|t}\mathbf{Q}_{i^*,2}\right)\widehat{i}_t^* + \mathbf{Q}_{mp}\varepsilon_{mp,t|t} \tag{29}$$

where $pr_{j,t|t}$ and $\varepsilon_{mp,t|t}$ are the Bayesian inference of the probability of being type j and the size of the monetary policy shock. Using the Kalman Filter, this inference is updated as:

$$\begin{aligned}\begin{bmatrix} pr_{1,t|t}\widehat{i}_t^* \\ pr_{2,t|t}\widehat{i}_t^* \\ \varepsilon_{mp,t|t} \end{bmatrix} &= \begin{bmatrix} \rho_{i^*} & 0 & 0 \\ 0 & \rho_{i^*} & 0 \\ 0 & 0 & 0 \\ & & \end{bmatrix} \begin{bmatrix} pr_{1,t-1|t-1}\widehat{i}_{t-1}^* \\ pr_{2,t-1|t-1}\widehat{i}_{t-1}^* \\ \varepsilon_{mp,t-1|t-1} \end{bmatrix} \\ &\quad + \mathbf{K}_g \begin{bmatrix} \widehat{i}_t^* - (pr_{1,t-1,t-1} + pr_{2,t-1|t-1})\rho_{i^*}\widehat{i}_{t-1}^* \\ dev_{mp,t} + (1-\psi_i)\psi_{i^*}pr_{2,t-1|t-1}\rho_{i^*}\widehat{i}_{t-1}^* \end{bmatrix}\end{aligned}$$

where $\mathbf{K}_g$ is the Kalman gain matrix. When monetary authority follows rule (14) under low credibility, $dev_{mp,t} = 0$, $\forall t$. However, the credibility problem prevents immediate full inference ($pr_{1,t|t} = 1$ and $pr_{2,t|t} = \varepsilon_{mp,t|t} = 0$) by the private sector, and the latter only learns gradually the true type of the central bank.

To obtain the Kalman gain matrix we form the matrices to apply the Kalman filter algorithm.[25] We define matrices $\mathbf{F}_\xi$, $\mathbf{Q}_\xi$, and $\mathbf{H}_\xi$ as:

$$\mathbf{F}_\xi = \begin{bmatrix} \rho_{i^*} & 0 & 0 \\ 0 & \rho_{i^*} & 0 \\ 0 & 0 & 0 \\ \end{bmatrix}, \mathbf{Q}_\xi = \begin{bmatrix} pr_{1,0|0}\sigma^2_{i^*} & 0 & 0 \\ 0 & pr_{2,0|0}\sigma^2_{i^*} & 0 \\ 0 & 0 & \sigma^2_{mp} \\ \end{bmatrix}$$

$$\mathbf{H}'_\xi = \begin{bmatrix} 1 & 1 & 0 \\ 0 & (1-\psi_i)\psi_{i^*} & 1 \\ \end{bmatrix}$$

where $pr_{j,0|0}$ is the prior probability of being monetary authority type j and $\sigma^2_{i^*}$ is the variance of the innovations in the foreign interest rate. Thus, $\mathbf{K}_g$ can be obtained as the limiting value of the following iterative process:

1. Initialization: obtain $\mathbf{\Omega}_0$ as the solution of $\mathbf{\Omega}_0 = \mathbf{F}_\xi \Omega_0 \mathbf{F}'_\xi + \mathbf{Q}_\xi$
2. Iteration: Given $\mathbf{\Omega}_{t-1}$ compute $\mathbf{K}_{g,t}$ and $\mathbf{\Omega}_t$ as:

$$\mathbf{K}_{g,t} = \mathbf{F}_\xi \mathbf{\Omega}_{t-1} \mathbf{H}_\xi \left[\mathbf{H}'_\xi \mathbf{\Omega}_{t-1} \mathbf{H}_\xi\right]^{-1}$$

$$\mathbf{\Omega}_t = \left(\mathbf{F}_\xi - \mathbf{K}_{g,t}\mathbf{H}'_\xi\right) \mathbf{\Omega}_{t-1} \left(\mathbf{F}'_\xi - \mathbf{H}_\xi \mathbf{K}'_{g,t}\right) + \mathbf{Q}_\xi$$

3. Iterate over step 2 until difference between $\mathbf{\Omega}_{t-1}$ and $\mathbf{\Omega}_t$ is close to zero.

[25] For further details on the algorithm, see for example, Hamilton (1994).

V. Appendix II: Sensitivity Analysis

Table A2: Sensitivity to price rigidities (θ_N)

	σ^{GDP}			σ^{π}		
	Low	Base	High	Low	Base	High
Regime θ_N	0.66	0.75	0.875	0.66	0.75	0.875
Full Credibility						
1 Instrument (MP)	0.26	0.27	0.29	0.86	0.83	0.79
2 Instruments (MP and FXI)	0.11	0.11	0.08	0.11	0.11	0.09
Imperfect Credibility						
1 Instrument	0.40	0.40	0.34	0.70	0.66	0.47
2 Instruments						
Imp. Cred. on MP	0.17	0.17	0.22	1.34	1.25	1.00
Imp. Cred. on FXI	0.15	0.14	0.12	0.50	0.49	0.47

Table A3: Sensitivity to wage rigidities (χ_w)

	σ^{GDP}			σ^{π}		
	Low	Base	High	Low	Base	High
Regime χ_w	0.66	0.875	0.95	0.66	0.875	0.95
Full Credibility						
1 Instrument (MP)	0.24	0.27	0.36	0.74	0.83	0.93
2 Instruments (MP and FXI)	0.11	0.11	0.13	0.12	0.11	0.13
Imperfect Credibility						
1 Instrument	0.23	0.40	0.54	0.67	0.66	0.67
2 Instruments						
Imp. Cred. on MP	0.18	0.17	0.22	1.22	1.25	1.30
Imp. Cred. on FXI	0.11	0.14	0.19	0.41	0.49	0.59

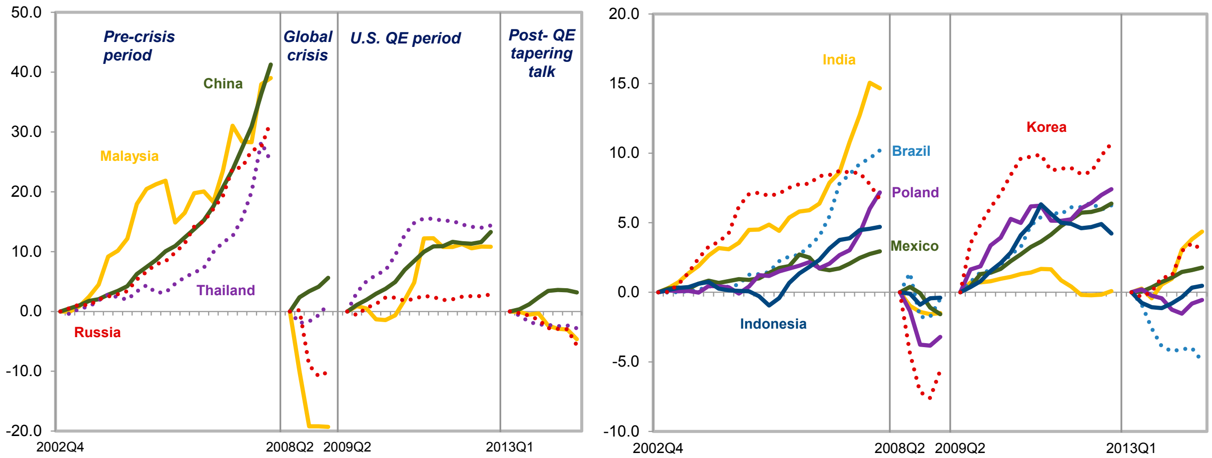
Table A4: Sensitivity to persistence of capital flows (ρ_{i^*})

	σ^{GDP}			σ^{π}		
	Low	Base	High	Low	Base	High
Regime ρ_{i^*}	0.7	0.95	0.98	0.7	0.95	0.98
Full Credibility						
1 Instrument (MP)	0.21	0.27	0.33	0.68	0.83	0.89
2 Instruments (MP and FXI)	0.15	0.11	0.22	0.27	0.11	0.18
Imperfect Credibility						
1 Instrument	0.23	0.40	0.49	0.41	0.66	0.75
2 Instruments						
Imp. Cred. on MP	0.05	0.17	0.24	0.42	1.25	1.49
Imp. Cred. on FXI	0.06	0.14	0.21	0.22	0.49	0.59

Table A5: Sensitivity to portfolio balance channel (ϱ)

	σ^{GDP}			σ^{π}		
	Low	Base	High	Low	Base	High
Regime ϱ	0.1	0.2	0.3	0.1	0.2	0.3
Full Credibility						
1 Instrument (MP)	0.36	0.27	0.23	1.10	0.83	0.70
2 Instruments (MP and FXI)	0.19	0.11	0.16	0.56	0.11	0.34
Imperfect Credibility						
1 Instrument	0.50	0.40	0.35	0.50	0.66	0.76
2 Instruments						
Imp. Cred. on MP	0.33	0.17	0.13	0.77	1.25	1.55
Imp. Cred. on FXI	0.16	0.14	0.22	0.34	0.49	0.88

Figure 1. FX Intervention in Selected Emerging Market Economies, 2002-14 1/
(cumulative by period, in percent of GDP)



Sources: International Financial Statistica; and authors' calculations.
1/ FXI estimated by substracting estimated interests on central bank foreign assets and liabilities from balance of payment net reserve flows. Non-spot interventions include aggregate short and long positions in forwards and futures in foreign currencies vis-à-vis the domestic currency (including the forward leg of currency swaps), and financial instruments denominated in foreign currency but settled by other means (e.g., in domestic currency), as reported in the IMF Reserve Template. See details in Adler et al (2015).

Figure 2.A. FX Intervention under Full Information

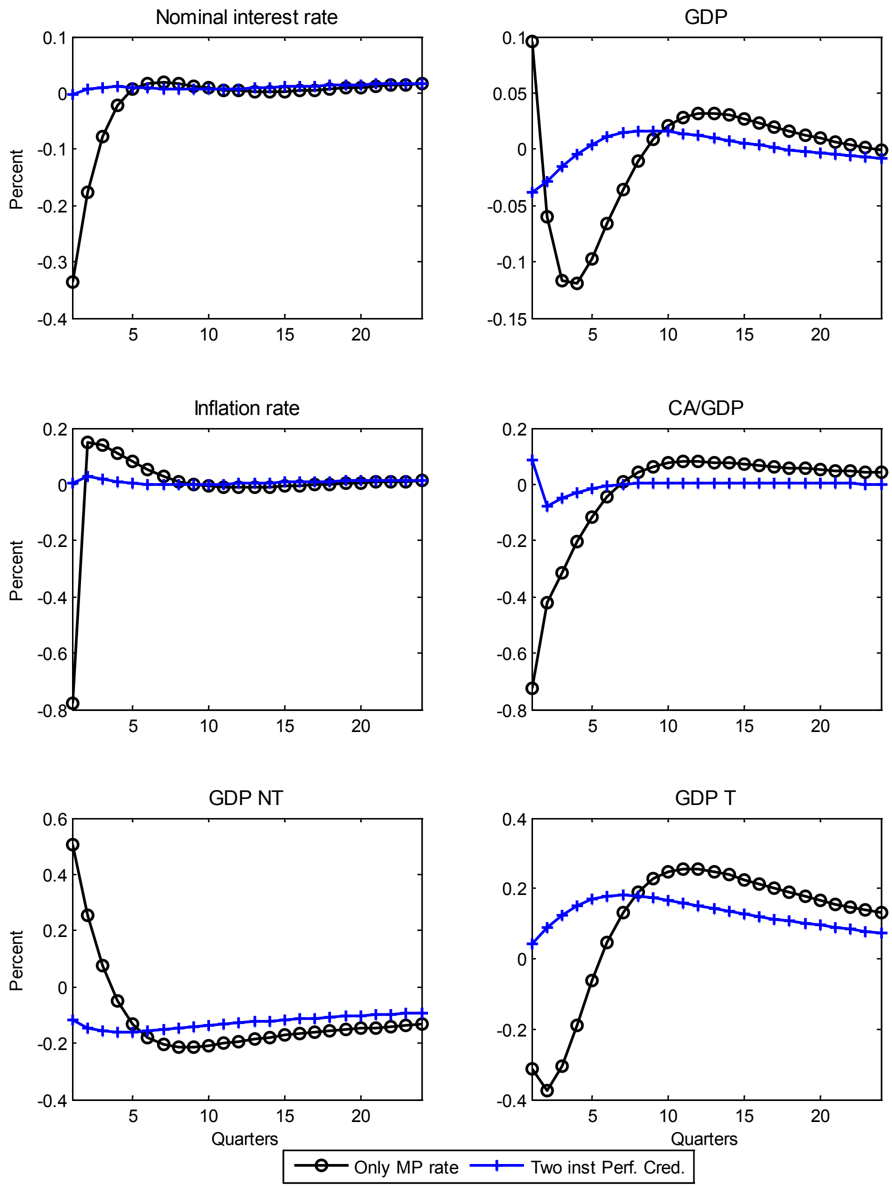


Figure 2.B. FX Intervention under Full Information

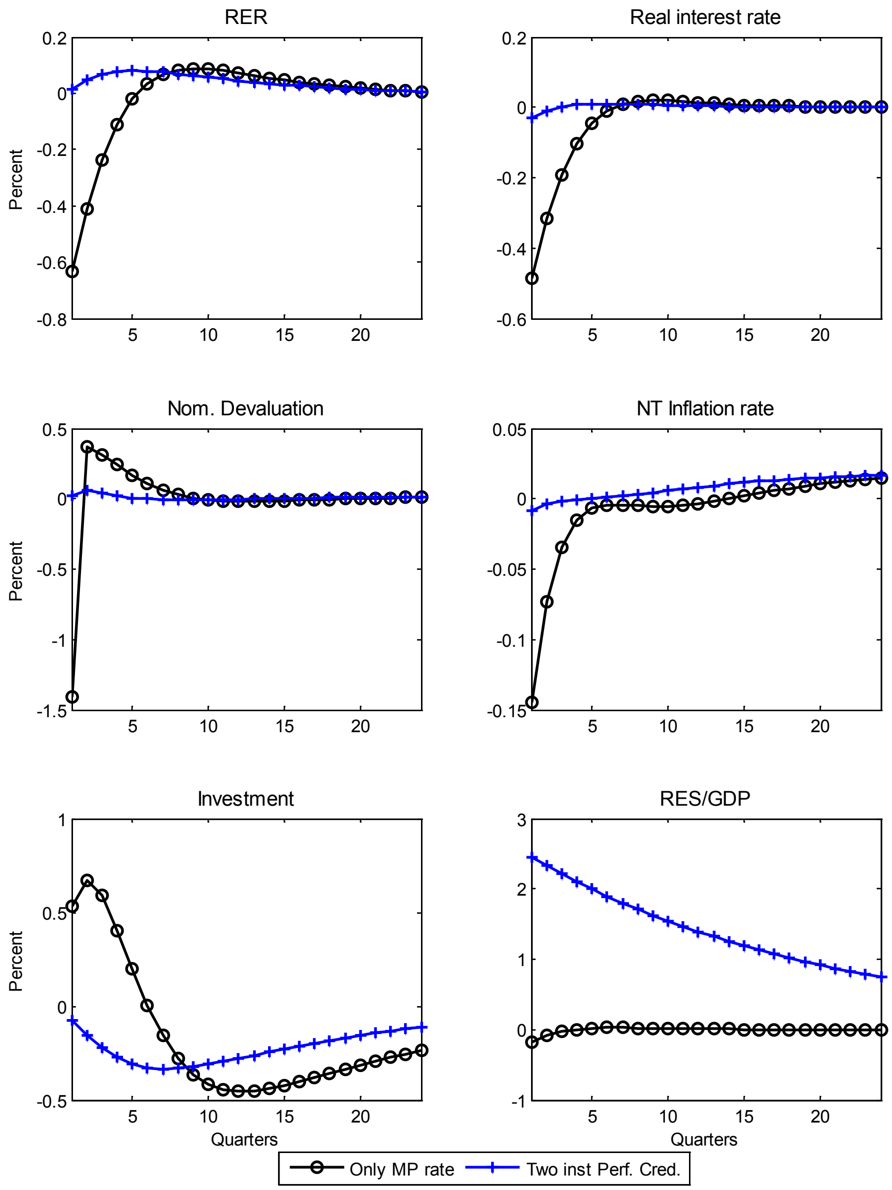


Figure 3.A. Monetary Policy under Policy Uncertainty

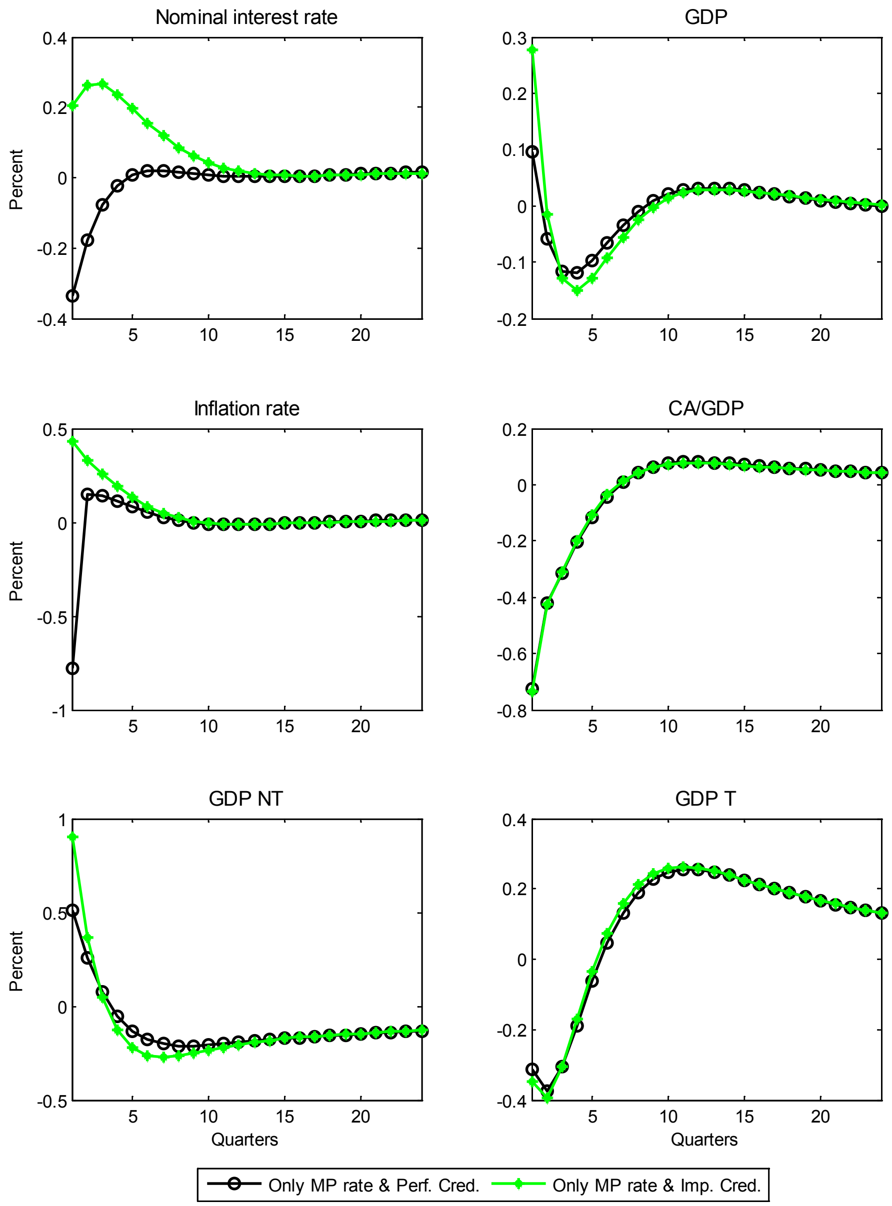


Figure 3.B. Monetary Policy under Policy Uncertainty

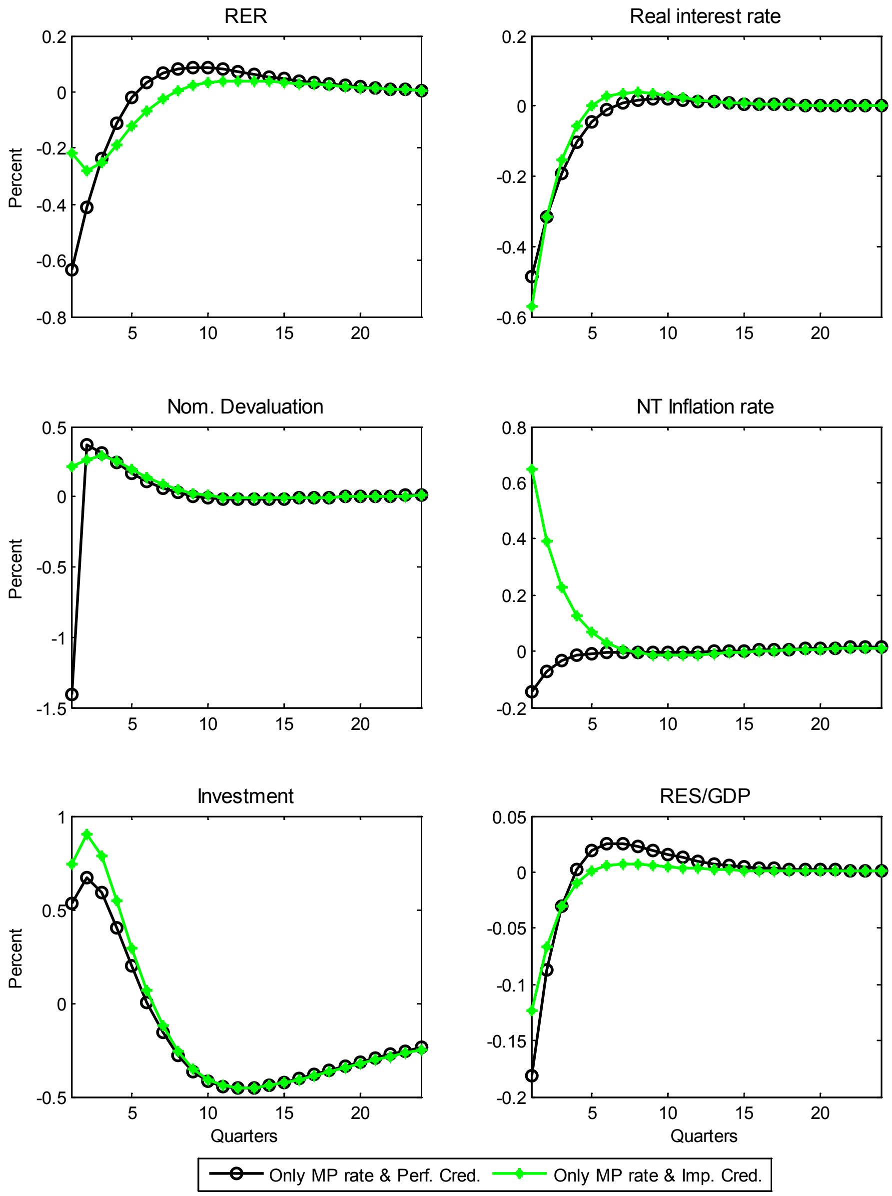


Figure 4.A. Monetary Policy and FX Intervention under Policy Uncertainty

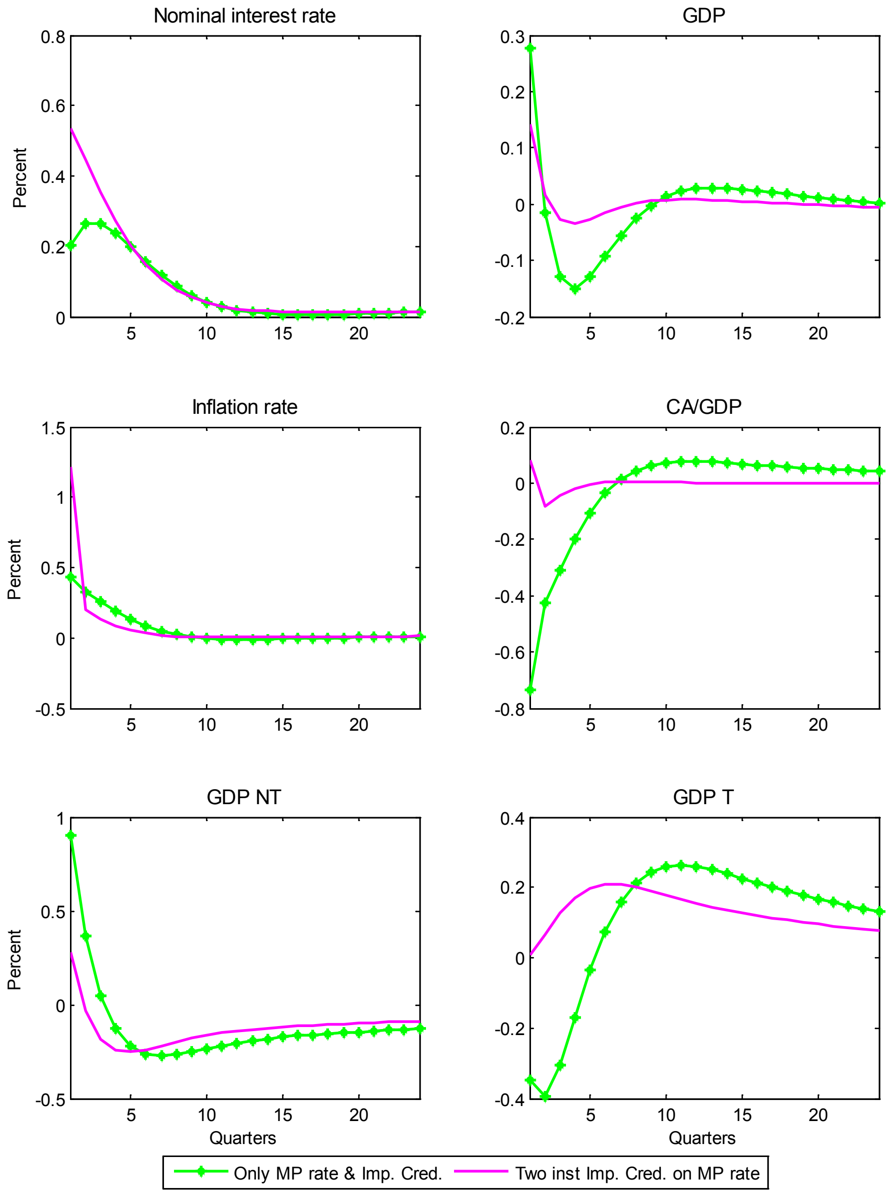


Figure 4.B. Monetary Policy and FX Intervention under Policy Uncertainty

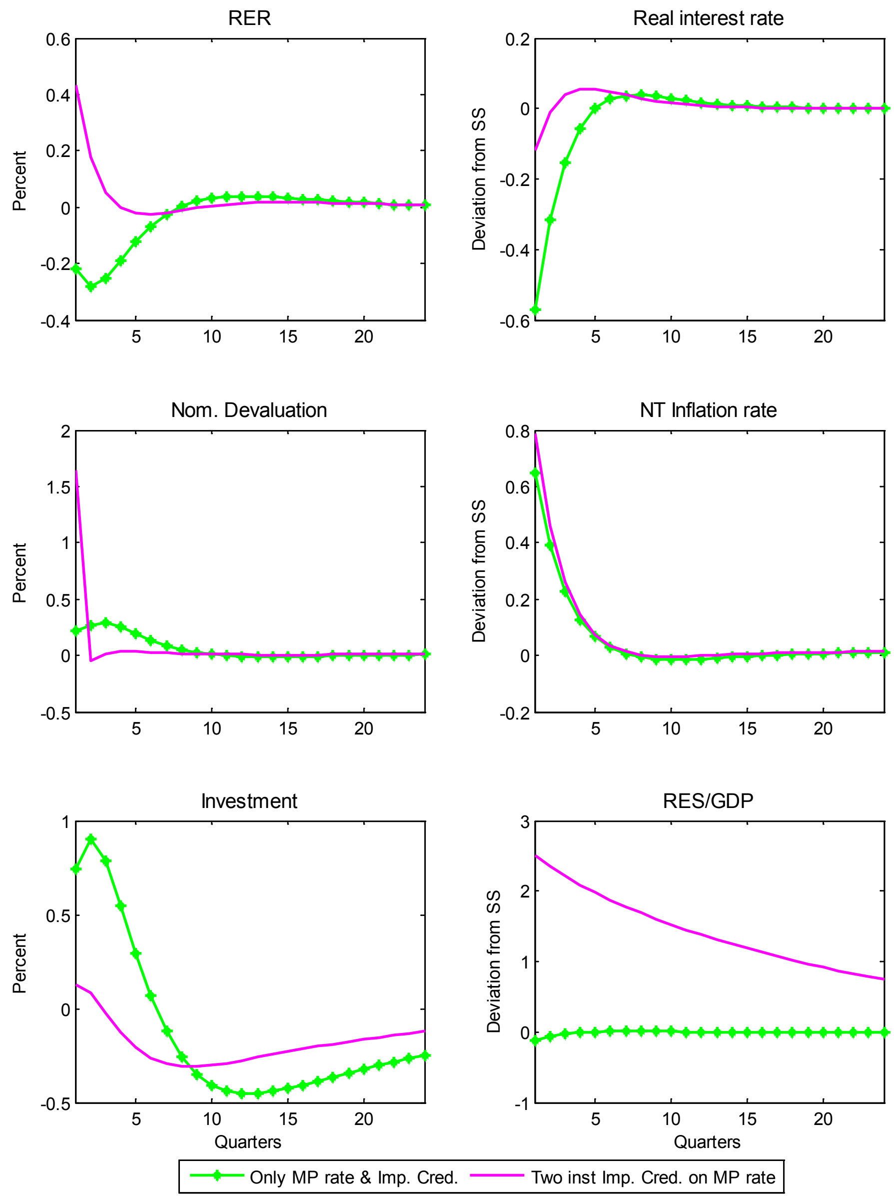


Figure 5. Output and Inflation Volatility under Perfect and Imperfect Credibility

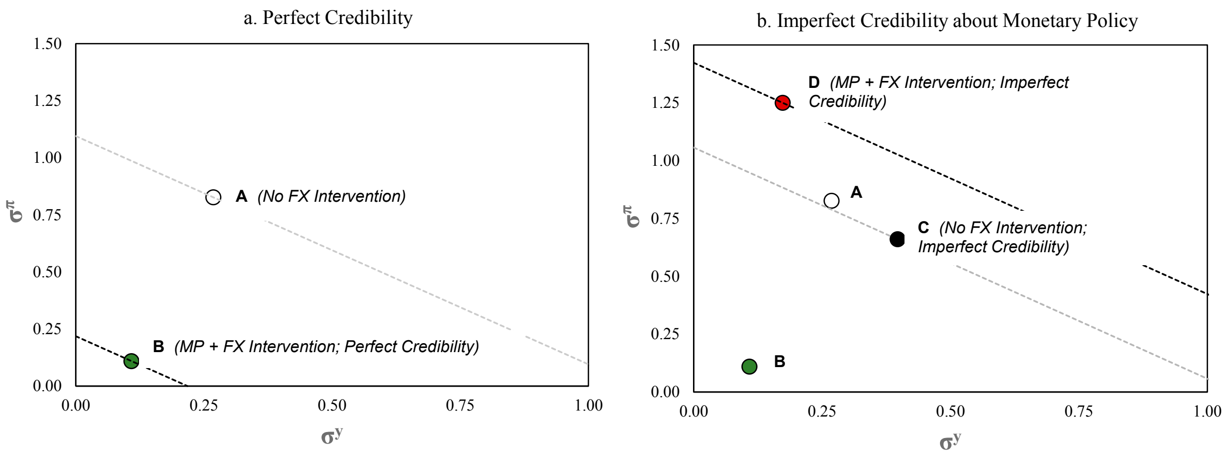


Figure 6. Monetary Policy Uncertainty and Gains from FX Intervention

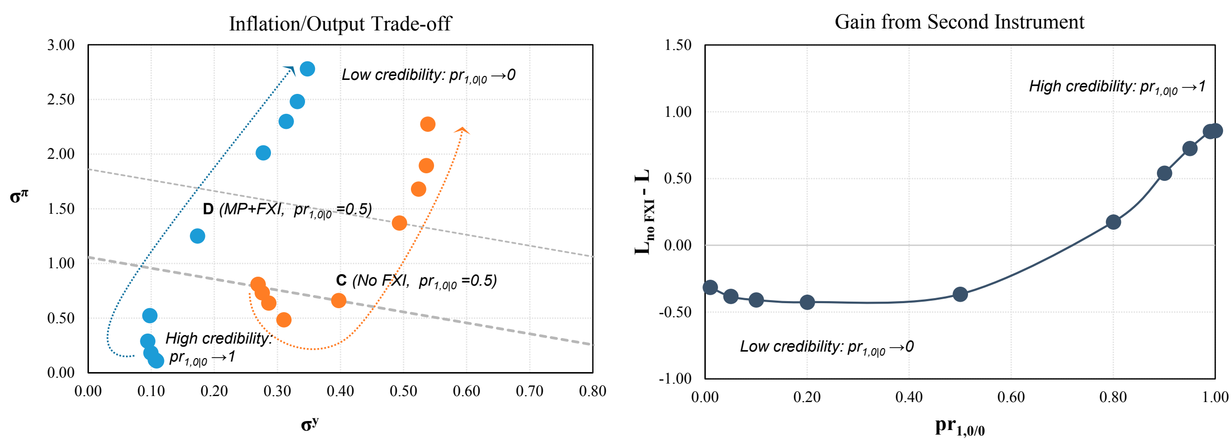


Figure 7. Optimal FXI under Monetary Policy Uncertainty

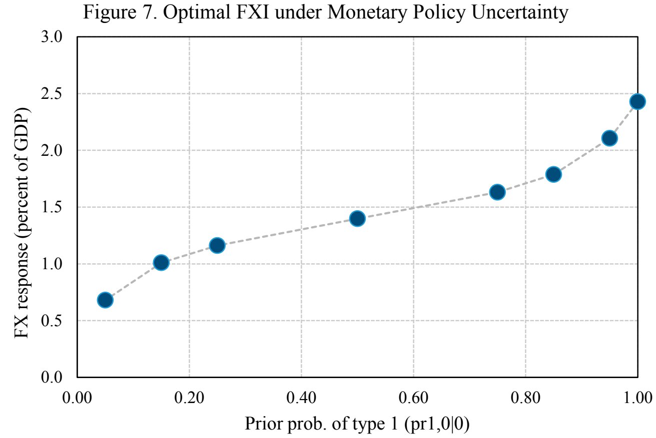


Figure 8.A. Exchange Rate Policy Uncertainty

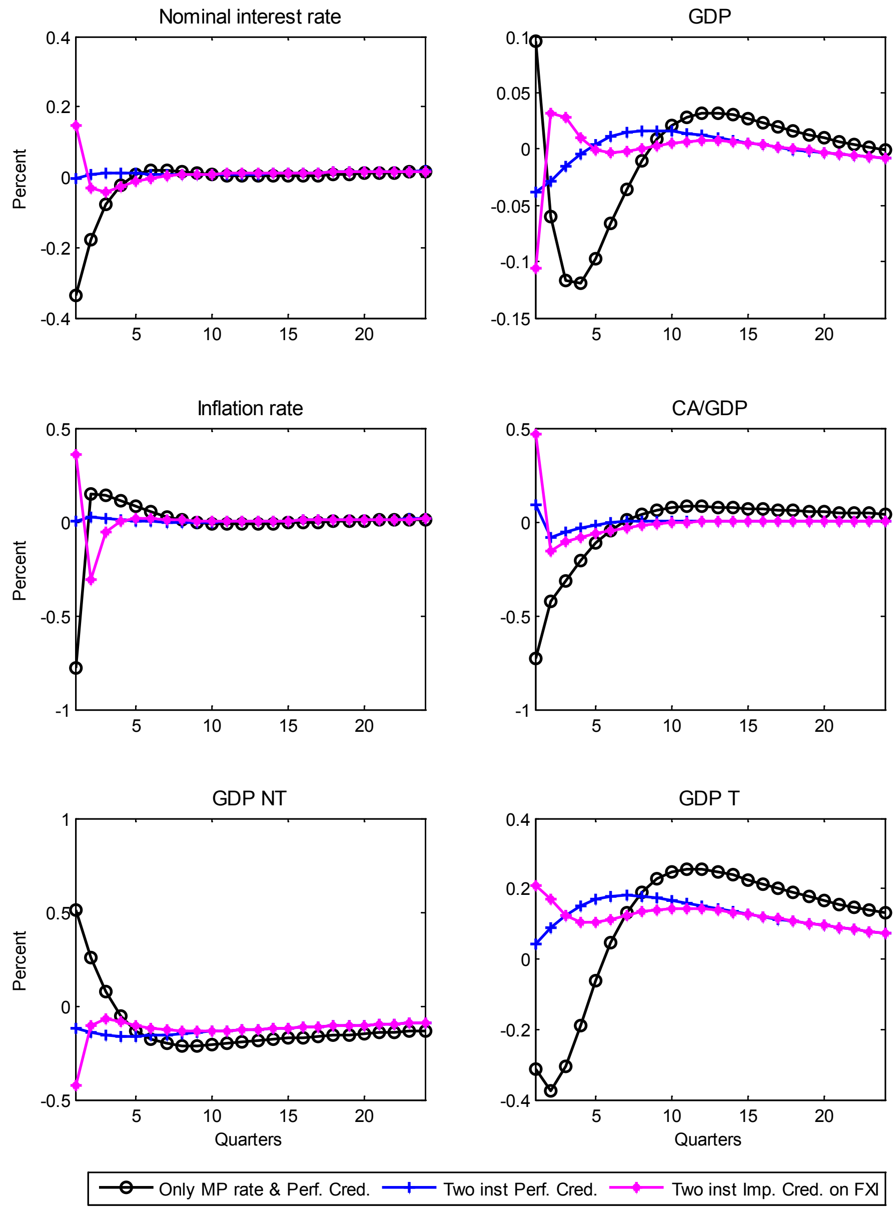


Figure 8.B. Exchange Rate Policy Uncertainty

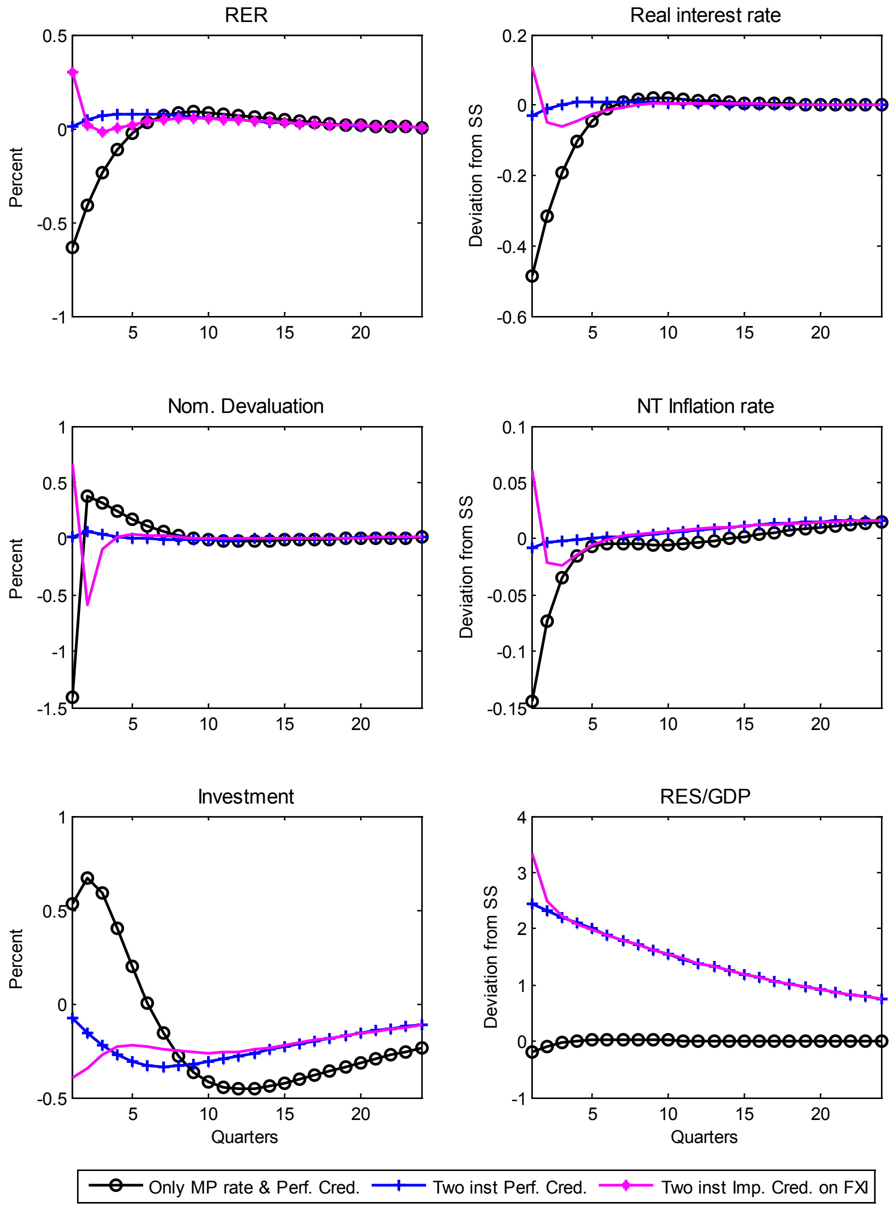


Figure 9. Exchange Rate Policy Uncertainty and Gains from FX Intervention