Overshooting Meets Inflation Targeting*

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Preliminary and Incomplete

When deciding on writing a paper to honor Rudi Dornbusch we were faced with two options. The first one was to think what he would have been thinking and working currently. Perhaps he would be writing and giving speeches all over the world about global imbalances and in particular on the US current account deficit. The other option was to refer to some of his major contribution to international macroeconomics. We decided to focus on the second one, and in particular in areas that had direct impact on central banking and monetary policy, and of course a key issue in emerging markets is exchange rate management. In this case the first thing that comes to mind is overshooting and volatility of exchange rates in flexible exchange rate regimes, the regime chosen by countries following inflation targets.

The most influential paper of Rudi Dornbusch was his *JPE* article on "overshooting." Although it is the most cited paper in international finance for a long time and a for a long shot, it is not his most important contribution. Rudi Dornbusch has his footprints all over the profession. His influence was much beyond his articles. He formed an impressive amount of students, which then become distinguished academics or policymakers, and until today we remember not only his papers, but also his deep remarks, his generosity and above all the marks that he left in many of us.

The overshooting paper was not only a great piece of research, but also pointed out to an important problem with flexible exchange rate, namely,

*Prepared for a session to honor Rudi Dornbusch, LACEA 10th Annual Meeting, Paris. This version is still incomplete, but it contains details on the presentation at the Conference.

excess volatility. The exchange rate could fluctuate beyond fundamentals, even when there is no imperfections in the foreign exchange market. This result is derived in a model with perfect capital mobility in which there are sticky prices. This is a strong reason for policymakers to suffer from fear of floating. This is also a reason for policymakers to be tempted to intervene under sharp fluctuations of the exchange rate.

In this paper we to re-examine the overshooting model. First, we discuss, in the original framework, the conditions for overshooting versus undershooting, and extend the model to consider monetary policy rules and imperfect capital mobility. And second, we frame the Dornbusch's contribution in a new keynesian dynamic general equilibrium model. In addition, in this way we can see whether the main results still hold in a general equilibrium model with microeconomic foundations.[1] Indeed, according to Obstfeld and Rogoff (1996) "On the theoretical plane, the Dornbusch overshooting model has several methodological drawbacks. The most fundamental is the model's lack of explicit choice-theoretic foundations. In particular there are no microfoundations of aggregate supply." This papers contributes to filling this gap. In addition, the lack of support for the model has been attributed to the fact that may be more likely the presence of undershooting rather than overshootingf. However, in the basic theoretical framework, the conditions to generate undershooting are rather contrived, namely, that the interest rate rises or the current account deficit narrows as result of a monetary expansion. We argue that most likely is that exchange rates are subject to many shocks that make difficult the identification of the pure effect of permanent monetary shocks. However, we also show that these models, even with overshooting, are unable to explain the much higher volatility of exchange rates than that of prices.

In the next section we describe the basic logic of overshooting. Then, in section 2 we present a simplified version of the original model. Section 3 presents a general equilibrium model with sticky prices, which then is calibrated and simulated in section 4. Section 5 concludes with discussion of issues for further research which are particularly relevant in the context of policymaking.

[1]For an insightful recent discussion of the overshooting model, see Rogoff (2002). In this paper we discuss, as Rogoff (2002) does, the difference between over and undershooting, but focusing on the impact on the interest rate. But we go beyond by analyzing the behavior of exchange rates in a more general framework.

1 The Basis of Overshooting

The logic for overshooting can be understood just by looking at the interest rate parity condition:

$$i_t = i_t^* + \mathrm{E}_t s_{t+1} - s_t. \tag{1}$$

Notation is the traditional, and s represents the log of the nominal exchange rate, measured as the domestic price of foreign currency. [2] The term $\mathrm{E}_t s_{t+1} - s_t$ corresponds to the expected rate of depreciation. Let's consider a period sufficiently long, so that $\mathrm{E}_t s_{t+1}$ is the long run equilibrium nominal exchange rate, denoted by $\bar{s}$.

Consider now a permanent monetary expansion, where M increases in a θ percent, this is $M_{t+1} = M_t(1+\theta)$. In any model where, as expected, money is neutral, the equilibrium exchange rate will rise also by θ percent. Therefore, $\bar{s}_{t+1} = (1+\theta)\bar{s}_t$.

Now, a monetary expansion will cause a reduction in the interest rate, and hence, there should be an *expected appreciation* of the domestic currency to compensate for the lower return in domestic currency. But, how can a currency that in the long-run depreciates, incurs in an appreciation in the transition to the equilibrium? The only possibility is that on impact the exchange rate depreciates, but beyond its long run equilibrium, so in the path to the equilibrium it appreciates. Hence, the exchange rate *overshoots* its long run equilibrium.

Note that the exchange rate does not adjust immediately to its long-run equilibrium, and for this is key the slow adjustment in prices, otherwise money would be neutral even in the short run since the exchange rate would immediately adjust to its equilibrium. The rigidity of prices is what generates changes in the interest rate by the equilibrium in the money market.

As long as the interest rate declines and the long-run exchange rate, as well as its expectations, increases, the only option is an overshooting. In this way, there is an appreciation on the equilibrium path.

Empirically the "overshooting" model has not been quite successful. It predicts that low interest rates should be correlated with depreciated exchange rate, something that could be the case under large monetary expansions and regime changes, but that it does not happen in normal circumstances. As it has argued by Rogoff (2002) and Obstfeld and Rogoff (1996), a possible explanation is that rather than having overshooting there is undershooting,

[2] It goes up when it depreciates.

this is, the exchange rate does not move beyond its long-run equilibrium.

To understand undershooting we can just look again at equation (1). There will be undershooting, under perfect capital mobility, if the interest rate instead of going down after a monetary expansion goes up. Then, the exchange rate will depreciate, but on the path to the equilibrium it will have to depreciate to offset the higher interest rate ($i > i^*$). According to equation (1), if the interest rate increases, there is a need for an expected depreciation on the path toward a depreciated exchange rate. Therefore, the initial jump in the exchange rate falls short of the equilibrium depreciation.

How can an undershooting happen? In the original model, a monetary expansion causes both a depreciation and an expansion of output. If the expansion of output is large enough, this could increase money demand to a point where it raises more than money supply, requiring a rise in the interest rate to equilibrate the money market. In terms of the model, the requirement is that output reacts strongly to the depreciation and the money demand, in turn, reacts strongly to output. In this case, the effects of the rise in interest rate on investment does not offset the depreciation from the point of view of aggregate demand.[3] We formalize this point in the next section.

Therefore, the undershooting requires a rise in the interest rate as result of a monetary expansion. This is unrealistic, and does not seem a good point of departure to explain potential empirical weaknesses of overshooting.

Other form to obtain undershooting, that we formalize in the next section, is to drop the assumption of perfect capital mobility. If we add a risk premium to equation (1), a monetary expansion that reduces interest rates still can be consistent with an expected depreciation if the risk premium falls more than the interest rate. However, this is also a condition difficult to hold in reality.

2 Overshooting Vintage 1976

The description of the overshooting has not needed any additional structure beyond uncovered interest rate parity. In order to grasp more intuition on the result here we present a simplified version of the model, and then some extensions. In this section we focus on the conditions that generate overshooting and undershooting. The latter could help to reconcile the empirical evidence of the correlation between interest rates and exchange rates. However, it is important to add the caveat that still we need to explain excessive volatility

[3]This cannot happen in a closed economy since the interest rate is the only connection between the money market and the aggregate demand.

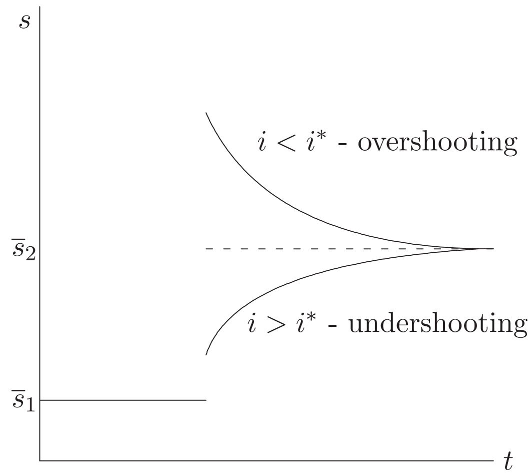

Figure 1: Monetary Expansion and Exchange Rate Adjustment

of the exchange rate with respect to that of prices, in which case overshooting still helps.

2.1 The original version

In continuous time and under perfect foresight, uncovered interest rate parity becomes:

$$i = i^* + \dot{s}. \tag{2}$$

Where $\dot{x}$ represents the derivative of x with respect to time. Since s is the log of the exchange rate, $\dot{s}$ is its rate of change.

Output is determined by the aggregate demand (IS) and inflation is given by a Phillips curve where an increase in the output gap reduces inflation. The equations for the IS and the Phillips curve are:

$$y = \bar{y} + \phi(s - p), \tag{3}$$
$$\dot{p} = \lambda(y - \bar{y}), \tag{4}$$

respectively. Note that the IS depends only on the real exchange rate, where p is the log of the price level, and the log of foreign prices is normalized to one. We have excluded, without loss of generality, the effects of interest rates on aggregate demand. The natural level of output is $\bar{y}$.

Finally, the money market equilibrium is given by:

$$m - p = -\eta i + \kappa y. \tag{5}$$

Substituting the aggregate demand on the Phillips curve we have the following law of motion for prices:

$$\dot{p} = \phi\lambda(s - p). \tag{6}$$

In turn, solving for the interest rate using the money market equilibrium and uncovered interest rate parity, and then substituting y by the aggregate demand, we have the following law of motion for the exchange rate:

$$\dot{s} = \frac{\kappa}{\eta}\bar{y} - \frac{1}{\eta}m - i^* + \frac{\kappa\phi}{\eta}s + \frac{1 - \kappa\phi}{\eta}p. \tag{7}$$

Now we can draw the phase diagram for the system using equations (6) and (7). The equation for $\dot{p} = 0$ is a the 45 degree line. Under the assumption that $\kappa\phi < 1$ the line for $\dot{s} = 0$ is negatively sloped as in figure 2. When $\kappa\phi > 1$ the $\dot{s} = 0$ is positively sloped, and the slope is less than one as in figure 3. In both cases the system is saddle path stable, and the saddle path corresponds to SS.

We examine the effects of a permanent monetary expansion. It is easy to check that money is neutral in the long-run, and both p and s in equilibrium increase in the same proportion as the monetary expansion. When $\kappa\phi > 1$ the monetary expansion causes on impact a jump in the exchange rate above its long-run equilibrium, so there is overshooting. The depreciation induces an output expansion that does not offset the increase in money, so the interest rate declines, and the exchange rate must appreciate in the path to the steady state. The economy jumps from E to B and then gradually appreciates along $S'S'$ to converge to E'.

Undershooting occurs when $\kappa\phi > 1$. In this case, the initial depreciation causes an output expansion that rises money demand more than the increase in supply, and hence the interest rate goes up. Consequently, the exchange rate depreciates on the path to the equilibrium. For this result to happen, one needs that the combination of the reaction of output to the exchange rate, given by ϕ, and the reaction of the money demand to output, given by κ, be strong enough to induce a rise in interest rate as result of the monetary expansion. The exchange rate jumps to B, but then gradually depreciates along the upward sloping saddle path to reach E'.

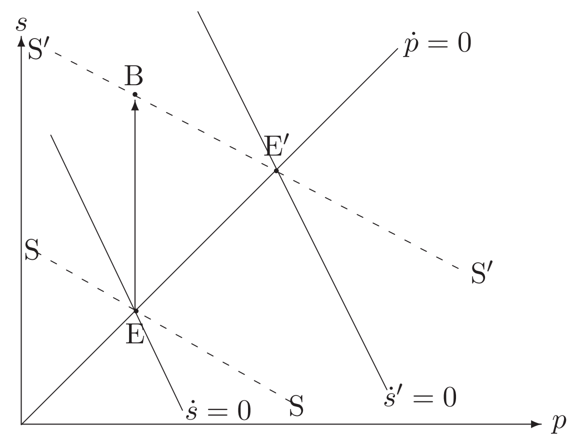

Figure 2: Overshooting

As argued before, it is difficult to think that realistically monetary expansions cause an increase in interest rates. Therefore, it does not look as a promising avenue to explain the lack of support that overshooting has on the data.

2.2 Monetary policy rules

A more promising area may be to model policymaking in a more realistic framework. A permanent increase of money, with no reason, is not necessarily what we observe in reality. Since Taylor (1990) we are more used to think that monetary policy reacts to news in the economy with the purpose of fulfil some objective. In general, it is the central bank's objective of price stability. We can accommodate other objectives, but what we want to emphasize is that money supply is changed as response to some shock in order to meet some objective regarding output fluctuations and inflation.

We can re-write Dornbusch's model assuming a monetary policy rule. In this case money is endogenous, and the interest rate adjusts to meet price stability. For this purpose we can replace the money demand equation by the following Taylor-type rule:

$$i = i^* + a(p - \bar{p}) + b(y - \bar{y}). \tag{8}$$

The only variation with the traditional Taylor rule is that we assume that

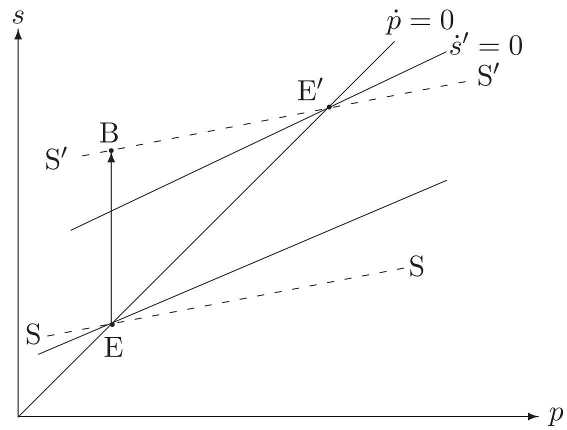

Figure 3: Undershooting

the objective of the monetary authority is the price level rather than inflation. The reason is that assuming, in the context of this model, an inflationary objective leads to the well-known problem of indeterminacy. The price level would be indeterminate, and it easy to show that the $\dot{s} = 0$ schedule is the same as the $\dot{p} = 0$ schedule, and any point in which $s = p$ would be an equilibrium. However, using the rule given by (8) it can be shown that the $\dot{s} = 0$ schedule is given by:

$$s = \left(1 - \frac{a}{b\phi}\right) p + \frac{a}{b\phi}\bar{p}. \tag{9}$$

Therefore, we reproduce the same diagrams as in the original Dornbusch's model, and when $\frac{a}{b\phi} > 1$ there is overshooting, while when $\frac{a}{b\phi} < 1$ there is undershooting. Instead of thinking in a permanent monetary expansion we can now interpret it as an increase in the price level target. However, this extension does not solve the basic problem with undershooting: in order to generate undershooting the interest rate must rise when the price level target increases. The increase in the target leads to a decline in the interest rate, but also there is an output expansion that tends to result in a rise in interest rate. Therefore, whenever b (corrected by ϕ) is large with respect to a the output effect of the monetary expansion dominates the rising of the price level target, leading to a rise in interest rate.

2.3 Imperfect capital mobility

Until now we have assumed that capital is perfectly mobile. Frenkel and Rodriguez (1982) argued that the limits to capital mobility may explain slower adjustment of exchange rates than prices and output. We can assume that countries face an upward-sloping supply of foreign financing. There is a risk premium that depends on the amount of borrowing, in this case on the negative value of net exports, which in our notation are represented by $\phi(s-p)$. Hence, we can write uncovered interest parity as:

$$i = i^* + \dot{s} - \beta\phi(s-p). \tag{10}$$

Where β represent the extent of capital market imperfections. The risk premium is increasing with the current account deficit.[4] If β is zero we are back to full capital mobility. As β increases it becomes more important the balance in the current account as a determinant of the exchange rate vis-a-vis the parity condition.

This representation is the same as the traditional way models of the 80s used for imperfect capital mobility. For example Frenkel and Rodriguez (1982) assume that under imperfect capital mobility the exchange rate is determined by the equilibrium in the balance of payments, where the capital account was an increasing function of the interest rate differential (in domestic currency), which can be written, in our formulation, as $-\phi(s-p) = \gamma(i - i^* - \dot{s})$. Tis is the same as our parity condition just by recognizing that $\gamma \equiv 1/\beta$.

Using equation (10) to obtain $\dot{s}$ as a function of s and p, we have the following expression for the $\dot{s} = 0$-schedule:

$$s = \left(1 - \frac{1}{\phi\kappa + \eta\phi\beta}\right)p + \frac{m + i^*\eta - \kappa\bar{y}}{\eta}. \tag{11}$$

When $\beta = 0$ we have the result of perfect capital mobility, in which overshooting occurs whenever $\phi\kappa < 1$. However, under imperfect capital mobility it is possible to have both *decline interest rate and undershooting* as a result of a monetary expansion. In the limit, when $\beta \to \infty$, the coefficient on p is positive and equal to one, in which case there is indeterminacy. Indeed for all $\beta > (1-\kappa\phi)/\eta\phi$, the slope of $\dot{s} = 0$ is positive and we have undershooting. Assume the extreme case where the money demand does not depend on income ($\kappa = 0$). This is sufficient for overshooting under perfect capital mobility since there will be a decline in the interest rate after a monetary expansion.

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[4] It is trivial to generalize the condition to allow for minimum risk premium to insure higher domestic interest rates.

Under imperfect capital mobility, however, we can still have undershooting and a decline in interest rate. For this we need a large value of β. The monetary expansion will cause a decline in interest rate and a depreciation of the currency, which will keep depreciating towards the new steady state.

The mechanics of undershooting can be understood examining (10). The decline in interest rate may be consistent with an expected depreciation if the risk premium declines more than the decline in the interest rate. The later effect is due to the initial depreciation that generates an improvement in the current account that reduces the risk premium. Of course it also seems unrealistic that a monetary expansion may cause a decline in the risk premium large enough to offset the arbitrage effects of a reduction of the domestic interest rate.

Although the results of Dornbusch's model extended to imperfect capital mobility are appealing, they still have some uncomfortable features. First, the monetary expansion causes the current account balance to improve, something not fully convincing. In principle, the decline in the interest rate should spur expenditure and, excluding the switching effects of the exchange rate, deteriorate the current account. Second, at a more formal level, the modelling of the risk premium is still a shortcut. The risk premium should depend on the stock of foreign liabilities rather than flows. Moreover, perhaps government liabilities are the most relevant factors influencing risk premia.

From the exercises analyzed int his section we can conclude that adding a monetary policy rule does not generate plausible undershooting. Although undershooting can still happen with imperfect capital mobility its implications regarding the risk premium and the current account are rather counterintutive. But, as argued before, monetary policy responds to many different shocks, rather than simply permanent monetary expansions, and its evolution will depend on the nature of the shock. The purpose of the next section is to analyze the evolution of the exchange rate in a general equilibrium model with sticky prices.

3 Exchange Rates in a Dynamic New-Keynesian General Equilibrium Model (DNK)

In this section we analyze the dynamics of the exchange rate in a standard new-keynesian model.

The equations of the model are:

AGGREGATE DEMAND. It is a traditional IS curve derived from the Euler equation of the maximization of the utility of consumption by household.

$$y_t = \mathrm{E}_t y_{t+1} + \phi_\pi \mathrm{E}_t \pi_{H,t+1} - \phi_e(\mathrm{E}_t s_{t+1} - s_t) - \phi_i i_t + \epsilon_{y,t} + (1-\rho_z)\epsilon_{z,t}. \quad (12)$$

Where y is the output gap, i the nominal interest rate, ϵ_y is a shock to aggregate demand, and the parameters ϕ are all positive. π is inflation and π_h is the inflation rate of home goods. The productivity shock, (ϵ_z), affects aggregate demand. The reason is that the aggregate demand is derive from the Euler equation of the household utility maximization problem, in which the expected path of the level of natural output affects the consumption choice (see Gali and Gertler, 1999).

Aggregate supply. The aggregate supply is a new-keynesian Phillips curve derived rom the first order condition of the price setting problem of firms.

$$\pi_{H,t} = \beta \mathrm{E}_t \pi_{H,t+1} + \lambda_y y_t + \lambda_q(s_t + p_t^* - p_{H,t}) + \epsilon_{\pi,t}, \quad (13)$$

and

$$\pi_t = \gamma \pi_{H,t} + (1-\gamma)(s_t - s_{t-1}). \quad (14)$$

This equation is derived from a Calvo type price setting behavior. Price setters are forward looking when setting prices, and hence the Phillips curve is forward looking and displays no inertia. The inflationary shock (cost-push) is represented by ϵ_π.

Uncovered interest parity condition. It is given by equation (1):

$$i_t = i_t^* + \mathrm{E}_t s_{t+1} - s_t. \quad (15)$$

Monetary Policy Rule. As traditional in the literature we assume that the central bank adjust gradually the interest rate to its objective $(\bar{\imath})$:

$$i_t = (1-\rho_i)\bar{\imath}_t + \rho_i i_{t-1}. \quad (16)$$

In addition, the objective of the central bank is governed by the following forward-looking monetary rule:[5]

$$\bar{\imath}_t = \chi_\pi(\mathrm{E}_t \pi_{t+k} - \bar{\pi}) + \chi_y y_t + \chi_s s_t + \epsilon_{i,t}, \quad (17)$$

[5] We do not derive form optimality this rule, but it is a good approximation to describe central bank's behavior. We have also worked out simulations with different rules, but found that this is the one that is best suited for the points we want to rise here.

where $\bar{\pi}$ is target inflation and ϵ_i is a shock to the interest rate (to the monetary policy rule). We allow monetary policy to react to the exchange rate. When $\chi_s = 0$ there is a flexible exchange rate. But, for positive values, there is an exchange rate objective, which is achieved through unsterilized intervention.

Shocks and Stochastic Processes. There are several shocks that can hit the system. All of them are assumed to be AR(1) process, and the AR(1) coefficient is denoted by ρ_j, where j is the stochastic variables. The cost-push shock is ϵ_π. The aggregate demand is subject to productivity shocks and demand shocks. The later could be a shock to world economic activity, or any other shock that change any of the components of domestic expenditure. The shock to the monetary policy rule could be the result of imperfect controllability of monetary policy or simply changes in the preferences of the policymaker, for example due to changes in the inflation target. The external interest rate is also assumed to follow and AR(1) process. In sum, we have the following shocks: $\epsilon_{\pi,t}$, $\epsilon_{z,t}$, $\epsilon_{y,t}$, $\epsilon_{i,t}$ and i_t^*.

4 Calibration and Simulations

This section describes the results of some quantitative experiments indicating how different shocks can influence exchange rate dynamics within the DNK framework. Specifically, the paper considers four types of shocks: inflation target, foreign interest rate, technology, and cost push shocks.

4.1 Model Parametrization

For parameter values, standard values that appear in the traditional related literature are chosen, which are in order of magnitude with Chilean estimations.

The following parameter values are selected both from traditional related literature and from current Chilean data. The quarterly discount factor is set at $\beta = 0.99$. The share of domestic goods in total home consumption is assumed to be $\gamma = 0.51$, which is equivalent to the average share of Chilean imports in its GDP over the period 2000-2005. The probability that a firm does not change its price within a given period, α, is set equal 0.75, which implies that the frequency of price adjustment is four quarters. The price demand elasticity or the degree of monopolistic competition, θ, is set at 4.33. It is assumed that $\sigma = 1$, which corresponds to log utility, and it is also assumed that the elasticity of substitution between domestic and foreign goods, η, equals 1.5.

The baseline policy rule (equation (17)) is a Taylor rule where the degree of interest rate smoothing, ρ_i, is equal to 0.7 and the coefficient associates to inflation and output are $\chi_\pi = 1.5$ and $\chi_y = 0.5$, respectively. For the exchange rate we consider two cases. For flexible exchange rate we set $\chi_s = 0$ and for managed exchange rate we use $\chi_s = 2.8$. Finally, the serial correlation parameters for the shocks are set equal to 0.8.

4.2 Model Solution

The dynamic system is given by equations[6] (12), (14), (15), (17), and by the definition of nontradable inflation, $\pi_t^{NT} = p_t^{NT} - p_{t-1}^{NT}$. In matrix form, the system is the following

$$E_t[k_{t+1}] = Ak_t + Bv_t, \tag{18}$$

where k_t is a vector of endogenous variables, $k_t = \left(x_t^{NT}, \pi_t^{NT}, s_t, i_{t-1}, p_{t-1}^{NT}\right)'$, A is a matrix of 5 by 5 matrix of coefficients, B is a matrix of 5 by 4 matrix of coefficients, and v_t is the vector of shocks.

The dynamic system has two predetermined variables: i_{t-1} and p_{t-1}^{NT} , and three nonpredetermined variables: x_t^{NT}, π_t^{NT}, and s_t. Thus, as shown in Blanchard and Kahn (1980), if the number of eigenvalues of A outside the unit circle is equal to the number of nonpredetermined variables – in our case three – then there exists a unique rational expectations solution to system (18).

The strategy is to transform the model into a canonical form. Let $A = QJQ^{-1}$, where J is the Jordan matrix associated with A, and Q is the corresponding matrix of eigenvectors. We define the vector of canonical variables as $w_t = Q^{-1}k_t = (u_t, z_t)'$, where u_t and z_t are associated with the unstable and stable eigenvalues, respectively. Let $J = \begin{pmatrix} J_u & 0 \\ 0 & J_z \end{pmatrix}$ and $Q = (Q_u, Q_z)$ be the corresponding partition of the Jordan matrix and matrix of eigenvectors, respectively. Thus, we can rewrite system (18) as

$$E_t \begin{pmatrix} u_{t+1} \\ z_{t+1} \end{pmatrix} = \begin{pmatrix} J_u & 0 \\ 0 & J_z \end{pmatrix} \begin{pmatrix} u_t \\ z_t \end{pmatrix}. \tag{19}$$

The canonical system requires that we set $u_t = 0$, $\forall t$, to rule out explosive solutions. If the number of eigenvalues outside the unit circle is equal to the number of nonpredetermined variables, the appropriate normalization choice

[6] Appendix X.X considers the system of equations including the real exchange rate, as in Svensson's model, instead of nominal exchange rate.

is $z_t = \begin{pmatrix} i_{t-1} \\ p_{t-1}^{NT} \end{pmatrix}$. We know that i_{t-1}, p_{t-1}^{NT} are predetermined, therefore $z_{t+1} = E_t[z_{t+1}]$ and this implies that $z_t = \varphi_z z_{t-1}$, where φ_z is a 2 by 2 matrix with the two stable eigenvalues in the diagonal. Therefore, this type of equilibrium implies that output, inflation, real exchange rate, and the interest rate converge towards their steady states.

4.3 Results and Comparisons

Four types of aggregate shocks are considered: inflation target, foreign interest rate, technology, and cost push shocks. Each shock is a first-order process, as described above. Since all shocks are assumed to be AR(1), they are transitory with a persitent paramenter of 0.7. As Rotemberg and Woodford (1998) stress, one has to present unconditional standard deviations to obtain a policy evaluation criterion that is not subject to any problem of time consistency. In other words, the analysis does not impose any condition on the current state of the economy at the particular date at which the policy action is to be taken. Selected unconditional standard deviations for each shock are reported in tables 1 and 2 for all exercises.

A Dornbusch exercise under a DNK model To demonstrate the dynamic properties of the model, the example of an inflation target shock that hits the economy is considered (see Figure 4). This shock could be interpreted as a permanent monetary expansion as in the original Dornbusch exercise. The results are consistent with the original exercise where the exchange rate overshoots its long-run equilibrium. In particular, an inflation target innovation causes a reduction in the interest rate and hence, there should be an expected appreciation of the exchange rate to compensate for the lower return of domestic currency. As in the original case, the only possibility to combine a long-term depreciation together with an expected appreciation is to have, on impact, a nominal depreciation larger than the long-run equilibrium. And this is the case in our example given the uncovered interest parity condition and the exogeneity of the foreign interest rate. The nominal exchange rate depreciates on impact, and then stays persistently above the original steady state. Nominal rigidities further cause a significant drop in the real interest rate and an increase in the real exchange rate, which, in turn, induces an expansion of output and a rise on impact of CPI inflation.

Recall that under a foreign exchange intervention, the monetary authority gives some weight to exchange rate stabilization in its policy rule. Since an inflation targeting regime does not allow for a pure fixed exchange rate, the policy instrument is still the nominal interest rate. Thus, if the central bank exercises some control over the nominal exchange rate, the impact of an inflation target shock (and consequently its volatility) is more limited than the case without foreign exchange intervention. The only exception is the nominal interest rate that tends to react more if the nominal exchange rate is managed because the overshooting feature is not present and hence the fall in the interest rate is not compensated by fluctuations in the exchange rate.

Foreign interest rate shock Under flexible exchange rates, the domestic nominal interest rate is not tied to the foreign interest rate. Consequently, a foreign interest rate shock (see Figure 5) produces a considerable nominal depreciation, which has a significant impact on CPI inflation. Similar, to the inflation target shock, the foreign interest rate shock results in a exchange rate that stays persistently above the initial steady state. Given that prices are sticky, the real exchange rate depreciates and, hence, has a positive impact on the output gap.

On the other hand, if the central bank exercises some control over the nominal exchange rate, the domestic interest rate rises to match the foreign disturbance that hits the economy, at least partially. Nominal rigidities further cause a significant rise in the real interest rate, which, in turn, induces a contraction in output.

Technology shock Figure 6 displays the impulse responses to a unit innovation of a domestic productivity shock. Uncovered interest parity implies an initial nominal depreciation followed by expectations of a future appreciation, as reflected in the response of the nominal exchange rate. The increase in domestic productivity and the required real depreciation lead, for given domestic prices, to an increase in CPI inflation.

The same figure displays the corresponding impulse responses under a managed exchange rate. The responses of output gap and inflation are qualitatively similar to the flexible exchange rate case. However, the nominal interest rate fell just half way without letting the currency to depreciate leads to an amplification of the responses of the output gap and domestic inflation.

Cost-push shock The cost-push shock has the most different implications of the other shocks considered in the model. In particular, a positive cost push shock has an inmediate impact in both domestic and CPI inflation. The latter increase several periods because the nominal exchange rate depreciates strongly on impact and it is followed by expectations of further depreciation.

In other words, the nominal exchange rate tends to undershoot its initial steady state. In our current calibration, the output gap increases on impact because the real exchange rate depreciates. However, as prices also increase relatively more than the nominal exchange rate, the real exchange rate appreciates with the consequent negative impact on the output gap.

In this case, under managed exchange rates, the cost push shock is absorbed by domestic prices and not by the nominal exchange rate. Therefore, the real exchange rate appreciates considerably with the consequent negative impact on output.

A permanent monetary expansion, as in the original the original Dornbusch's paper, leads to overshooting. We have model the monetary expansion as a transitory shock to the inflation target. Furthermore, under our calibration, the impact of both foreign interest rate and technology shocks entails a parallel reaction of the exchange rate: overshooting. While, under cost push shocks the exchange rate depreciates on impact and then rises again persistently above the steady state (undershooting). In the augmented Taylor rule we cannot properly define over- or under-shooting, but certainly the impact of shocks on the exchange rate are attenuated by fear of floating.

Unconditional Standard Deviations To evaluate the implications of alternative monetary rules, unconditional standard deviations are computed for each shock.[7] The main result is that flexible exchange rates tend to dominate managed exchange rates if the economy is hit by foreign interest rate, productivity, and cost push shock, while the reverse is true for the inflation target shock. This confirms the conventional wisdom that flexibility is better in the case of foreign and real shocks while pegging is preferable in the case of nominal shocks.

For instance, if we take the case of an inflation targeting shock, we can see that output volatility is lower in the flexible case than in the managed case because the adjustment is immediately reached through changes in the exchange rate and not through changes in the price level. CPI inflation also differs across exchange rate regimes. If the central bank can influence the exchange rate, inflation volatility is consistently lower than an economy with fully flexible exchange rates.

[7] All the shocks are independent and identically distributed shocks with zero mean and variance $\sigma_{\overline{\pi}}^2 = 0.25$, $\sigma_{i*}^2 = 0.25$, $\sigma_z^2 = 1$, and $\sigma_\pi^2 = 0.25$.

Table 1: Taylor rule: Unconditional Standard Deviations.

Variable	Inflation Target	Foreign Interest Rate	Productivity	Cost Push
Output	2.18	0.78	0.22	3.23
Domestic Inflation	0.21	0.29	0.03	3.61
Interest Rate	0.05	0.09	0.10	2.26
CPI Inflation	0.46	1.98	0.25	3.61
Real Exchange Rate	0.57	2.86	0.39	0.85
Real Interest Rate	0.47	1.91	0.20	2.65

Table 2: Augmented Taylor rule (including the exchange rate): Unconditional Standard Deviations

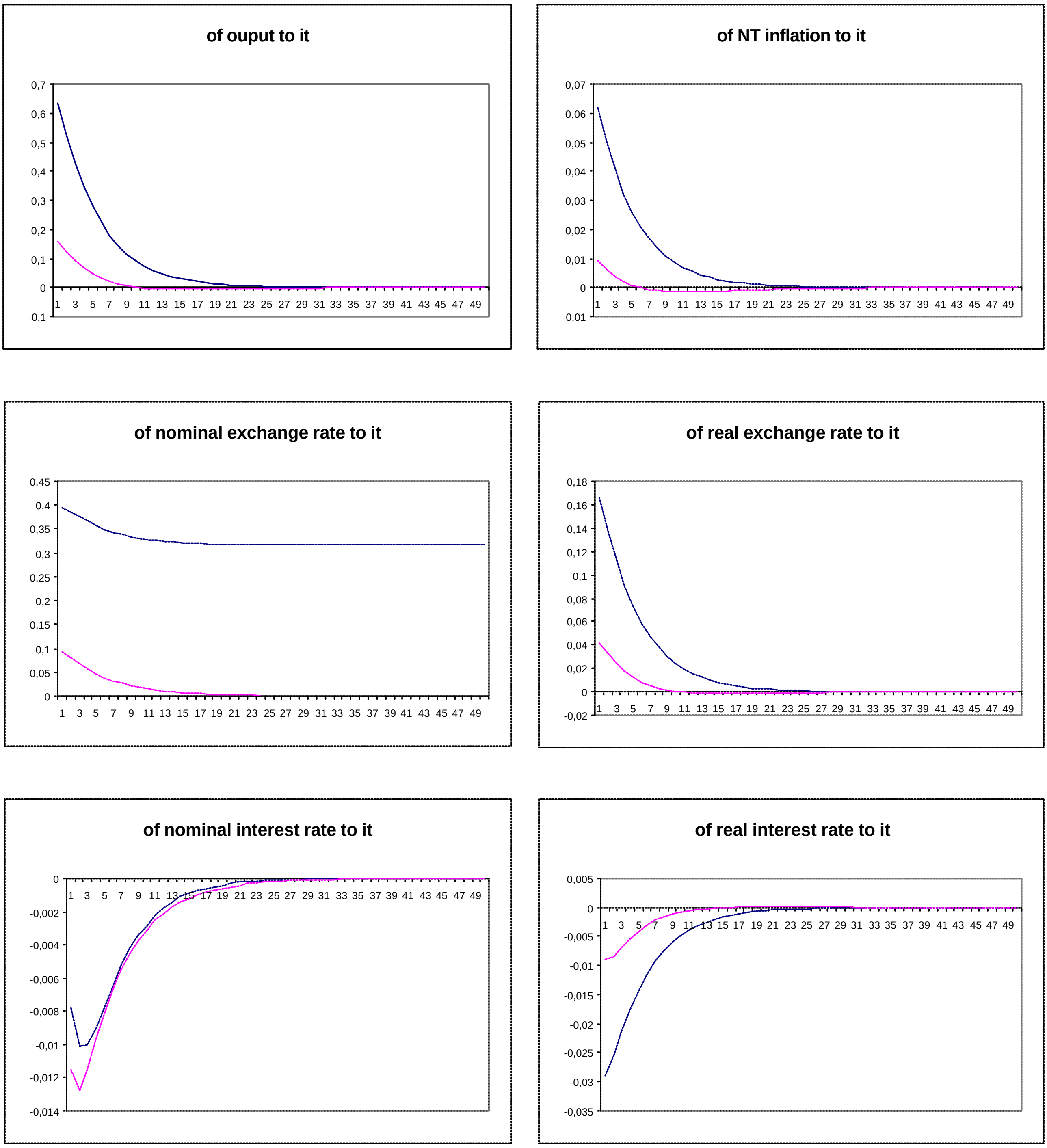
Variable	Inflation Target	Foreign Interest Rate	Productivity	Cost Push
Output	0.48	6.26	1.07	13.57
Domestic Inflation	0.03	0.22	0.04	1.78
Interest Rate	0.05	0.42	0.04	0.30
CPI Inflation	0.11	0.52	0.05	1.09
Real Exchange Rate	0.13	1.18	0.17	3.56
Real Interest Rate	0.11	0.80	0.04	0.91

5 Concluding Remarks

- Although this model could generate some realistic correlations still volatility of exchange rates is small with respect to the volatility of prices. This is a traditional problem with calibrated general equilibrium problems in its ability to replicate asset prices volatility. One possible way to reduce inflation volatility respect to exchange rate volatility may be to add more persistence in the inflation process adding some inertia in the Phillips curve.
- The model incorporates an exchange rate objective in the policy function, but does not allow for sterilized intervention. In addition, there is a target for the long-run. This could be a reasonable working assumption to compare rules, but not quite the best description of what actually policymakers do. Fear of floating is more related to suden and sharp changes in the exchange rate rather than targeting a specific level.

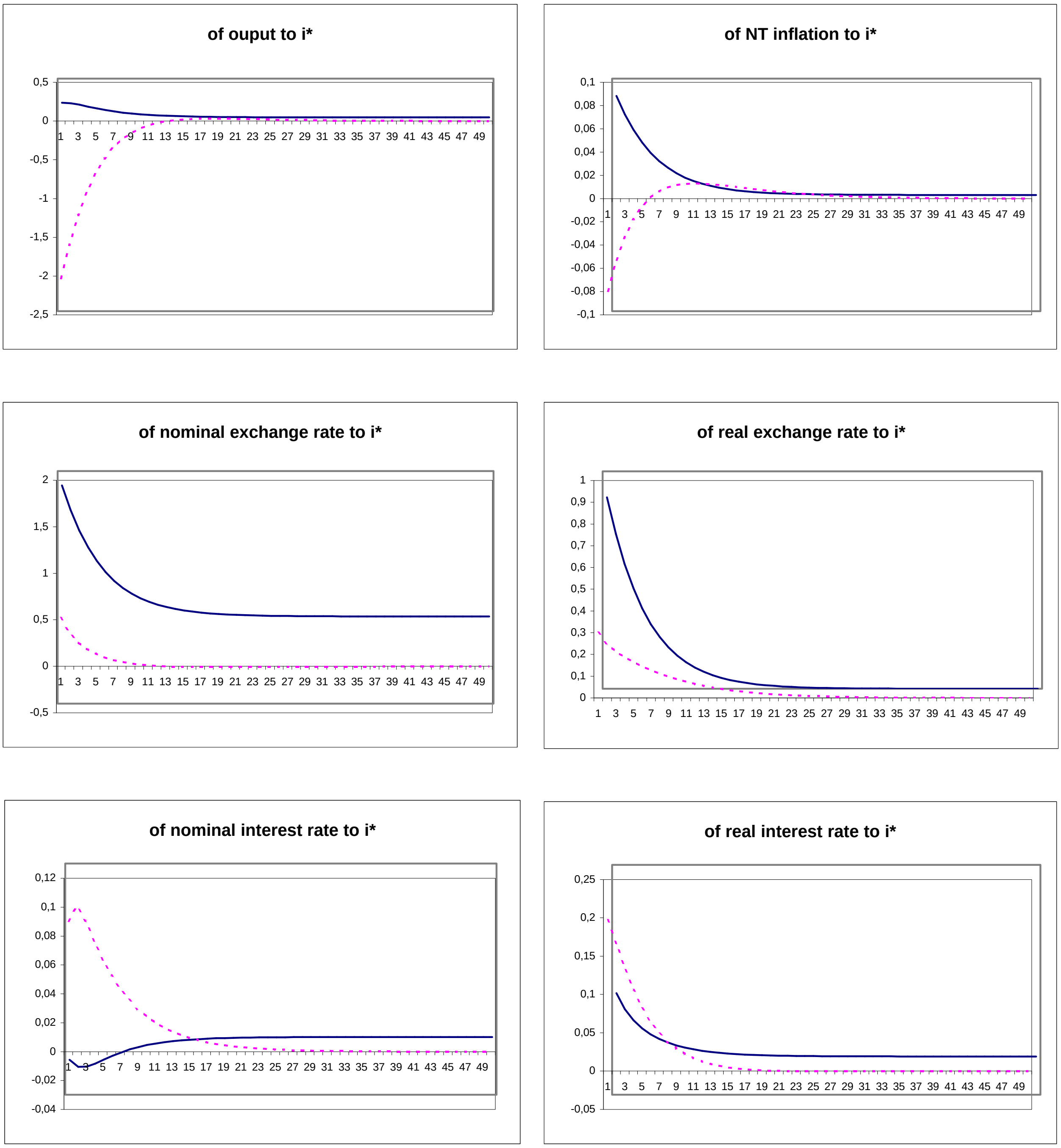
References

Figure 4. Impulse Responses: Inflation Target Shock



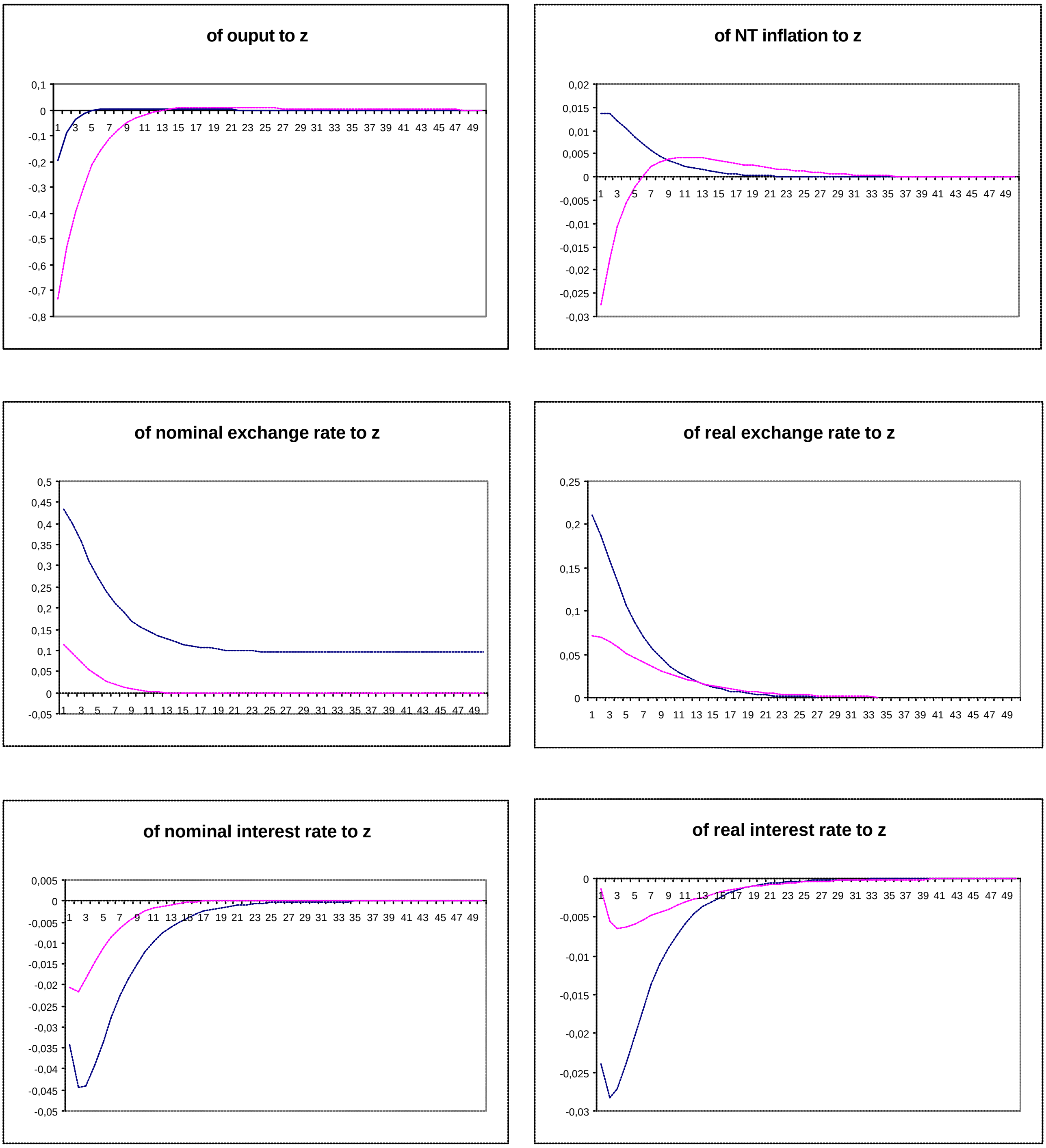
Note: The solid line corresponds to a flexible exchange rate and the dashed line to a managed exchange rate.

Figure 5. Impulse Responses: Foreign Interest Rate Shock



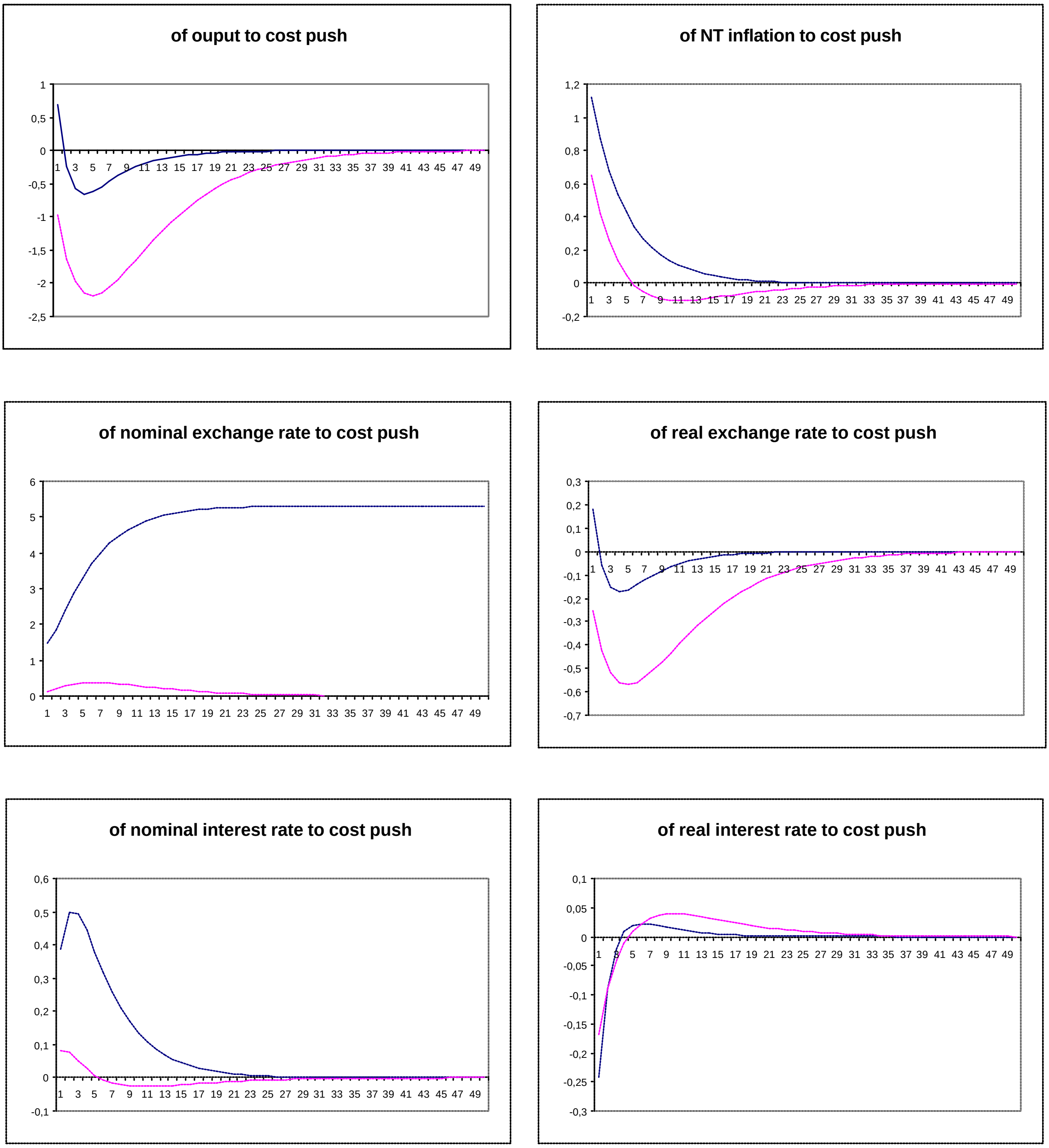
Note: The solid line corresponds to a flexible exchange rate and the dashed line to a managed exchange rate.

Figure 6. Impulse Responses: Productivity Shock



Note: The solid line corresponds to a flexible exchange rate and the dashed line to a managed exchange rate.

Figure 7. Impulse Responses: Cost Push Shock



Note: The solid line corresponds to a flexible exchange rate and the dashed line to a managed exchange rate.