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Resumen
El trabajo revisa el modelo de *overshooting* de Dornbusch; primero, para discutir las condiciones de sobrerreacción (*overshooting*) y subreacción (*undershooting*) del tipo de cambio, extendiendo el modelo para considerar reglas de política monetaria y movilidad imperfecta de capitales. En segundo lugar, para realizar una representación del modelo de Dornbusch en un modelo dinámico neokeynesiano que puede ser utilizado para analizar el impacto persistente de *shocks* de política monetaria, entre otras perturbaciones. El modelo considera el régimen de metas de inflación en un modelo de economía pequeña y abierta caracterizada por competencia imperfecta y rigidez de precios en el corto plazo. Los principales resultados del trabajo son coherentes con la contribución original de Dornbusch en la cual el tipo de cambio sobrerreacciona respecto de su equilibrio de largo plazo. También se concluye que los regímenes con tipo de cambio flexible predominan sobre los con tipo de cambio manejado o fijo en términos de volatilidad del producto y de la inflación frente a *shocks* reales, mientras que para *shocks* nominales se revierte la preferencia.

Abstract
This paper revisits Dornbusch's overshooting model; first, to discuss the conditions of overshooting and undershooting, extending the model to consider monetary policy rules and imperfect capital mobility. And second, to outline Dornbusch's representation in the context of a simple dynamic neo-Keynesian model that can be used to analyze the impact of persistent changes in monetary policy, among other shocks. The model considers inflation targeting in a small open economy setup, which is characterized by imperfect competition and short-run price rigidity. The main findings of the paper are consistent with the original contribution where the exchange rate overshoots its long run equilibrium. We also show that flexible exchange rates dominate managed exchange rates in terms of output and inflation volatility in the presence of real shocks, while for nominal shocks the reverse is true.

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1 Introduction

About thirty years ago, one of the most—perhaps "the most"— influential paper in international finance, the famous *overshooting* paper by Rudi Dornbusch (Dornbusch, 1976) was published. It is at least the most cited paper in the area and the most regularly used in courses of international finance (Rogoff, 2002). This paper introduced rational expectations in models of exchange rate determination, but also had important implications for asset pricing. It basically showed that exchange rates could fluctuate more than their fundamentals would warrant, leading to excessive volatility without the need to assume markets frictions. Indeed, this result is derived in a model of perfect capital mobility and sticky prices.

The overshooting paper not only was a great piece of research, but also had important policy implications. In the context of flexible exchange rates, not only among major currencies, but also increasingly with emerging market currencies, the excessive volatility is usually mentioned as the main disadvantage of free floating. A policy sequel is that overshooting is often used to justify intervening in foreign exchange markets. This is also a strong reason why policymakers suffer from "fear of floating" (Calvo and Reinhart, 2002).

From the empirical point of view, the evidence has been mixed and there are several dimensions in which the model performs poorly.[1] Starting from the "exchange rate disconnect puzzle" from Meese and Rogoff (1983), which shows that no structural model can predict exchange rates, not even monetary ones, there have been many attempts to explain exchange rate fluctuations. One important result from VARs has been that after a contractionary monetary policy shock the exchange rate appreciates, but the peak is reached several quarters after the contraction (see, e.g., Eichenbaum and Evans, 1995). This "delayed overshooting" contrasts with the sharp instant overshooting predicted by Dornbusch (1976). Faust and Rogers (2003) and, more recently, Bjørnland (2006) propose new identification restrictions that reduce this delayed overshooting. Although we do not to intend to address empirically the overshooting hypothesis, it is useful to review analytically the robustness of overshooting and which type of conditions are required to generate a different behavior of exchange rates.

In this paper we address two issues that are important from the standpoint of both the analytical and the empirical relevance of overshooting. The first is to examine the conditions under which the exchange rate undershoots instead of overshoots as in the original model. This could help to reconcile the evidence with Dornbush's model (Rogoff, 2002). However, in the basic theoretical framework, the conditions to generate undershooting are rather contrived, namely, that the interest rate rises as a result of a monetary expansion. Therefore, under perfect capital mobility, with the consequent uncovered interest rate parity, overshooting should

[1] For a recent discussion in the context of overshooting, see Rogoff (2002) and Bjørnland (2006).

be a natural outcome. We also show, that dropping perfect capital mobility as suggested by Frenkel and Rodriguez (1982) also requires special conditions. In such case it would be necessary for the current account deficit to narrow after a monetary expansion.

The second issue we examine here is the response of the exchange rate to different kinds of shocks in the context of a new Keynesian dynamic general equilibrium model, which are becoming standard in applied monetary policy. This helps to understand whether the main results still hold in a general equilibrium model with microeconomic foundations. 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 paper contributes to filling this gap. We show that the overshooting is robust to this more general and rigorous formulation. In addition, from an empirical standpoint, it is necessary to recognize that the movements in monetary policy and exchange rates depend on the nature of the shocks. And one criticism with traditional identification restrictions in VARs is that they ignore the contemporaneous correlation between exchange rates and monetary policy. The reaction of monetary policy will depend on the characteristics of the policy rule and the shocks that trigger that reaction. Indeed, in this framework, a pure permanent monetary shock as the one envisioned in Dornbusch's model, has to be interpreted as a change in the inflation or price level target.

It is important to note that the purpose of this paper is not to build a model that can explain the many empirical failures and puzzles of exchange rates, but to revisit the basic framework to argue that it is still a mechanism that should be present in most models of monetary policy and exchange rates. However, we also show that these models, even with overshooting, are unable to explain why exchange rates are so much more volatile than prices. In addition, the general equilibrium model we present in this paper can be used to analyze different policy rules depending on the degree of exchange rate management. We show that flexible exchange rates dominate managed exchange rates in terms of output and inflation volatility in the presence of real shocks, while the reverse is true for nominal shocks, which is consistent with the results from Mundell (1963).

In the next section we describe the basic logic of overshooting. Then, in section 3 we present a simplified version of the original model. Section 4 presents a dynamic general equilibrium model with sticky prices, which is then simulated in section 5. Section 6 concludes with a discussion of issues for further research which are particularly relevant in the context of policymaking.

2 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 one, and s represents the log of the nominal exchange rate, measured as the domestic price of foreign currency.[2] The term $\mathrm{E}_t s_{t+1} - s_t$ stands for the expected rate of depreciation. Let's consider a sufficiently long period, 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 by θ percent, this is, $M_{t+1} = M_t(1 + \theta)$. In any model where 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 depreciates in the long-run incur in an appreciation during the transition to the equilibrium? The only possibility is that on impact the exchange rate depreciates, but beyond its long-run equilibrium, so on the path to the equilibrium it appreciates. Hence, the exchange rate *overshoots* its long-run equilibrium (see Figure 1).

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

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

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

[2] It goes up when it depreciates.

of down after a monetary expansion. 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 (see Figure 1).

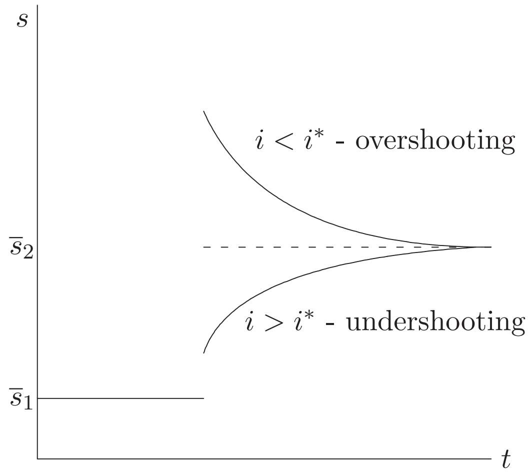

Figure 1: Monetary Expansion and Exchange Rate Adjustment

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 may increase money demand to a point where it rises more than money supply, requiring a rise in the interest rate to equilibrate the money market. In terms of the model, the requirement is for output to react strongly to the depreciation and the money demand, in turn, reacts strongly to output. In this case, the rise in the 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 starting point to explain the potential empirical weaknesses of overshooting.

Other form of obtaining 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.

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

3 Overshooting Vintage 1976

The description of overshooting has needed no additional structure beyond the 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 we still need to explain excessive volatility of the exchange rate with respect to that of prices, in which case overshooting still helps.

3.1 The original version

In continuous time and under perfect foresight, the 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. All parameters in what follows are positive. 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 1. 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 in 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 the uncovered interest rate parity, and then replacing y by the aggregate demand function, 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 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 1 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 in equilibrium, both p and s 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 on the path to the steady state. The economy jumps from E to B and then gradually appreciates along $S'S'$ to converge to E'.

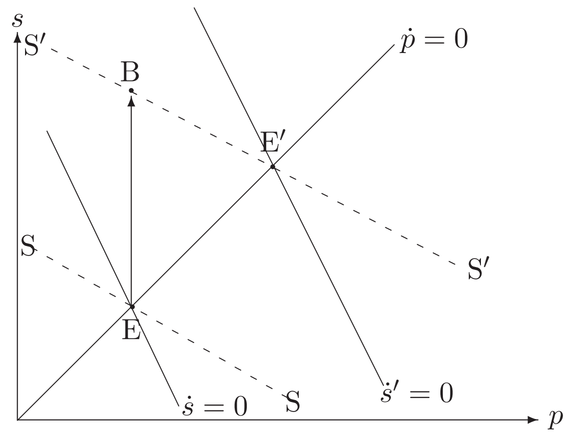

Figure 2: Overshooting

Undershooting occurs when $\kappa\phi > 1$. In this case, the initial depreciation causes an output expansion that raises money demand by 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, 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, needs to be strong enough to induce a rise in the interest rate as a result of the monetary expansion. The exchange rate jumps to B, but then gradually depreciates along the upward sloping saddle path to reach E'.

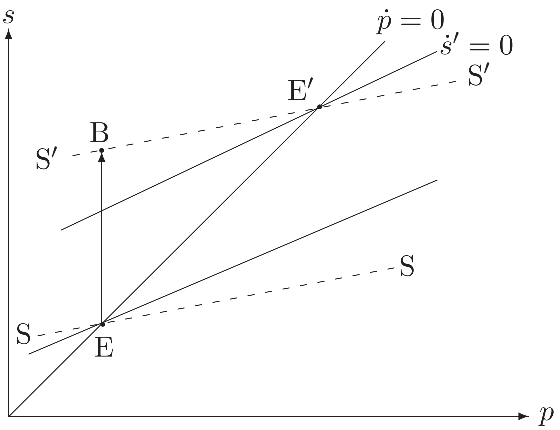

Figure 3: Undershooting

As argued before, it is difficult to think realistically that 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.

3.2 Monetary policy rules

A more promising area may be to model policymaking in a more realistic framework. A permanent increase in money supply, for no reason, is not what we often observe in reality. Since Taylor (1993), we are more used to think that monetary policy reacts to news in the economy with the purpose of fulfilling some objective. In general, central banks' objective is price stability. We can accommodate other objectives, but what we mean to emphasize is that money supply is changed as a response to some shock in order to meet some objective regarding output fluctuations and inflation.

We can rewrite 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 from the traditional Taylor rule is that the objective of the monetary authority is assumed to be the price level rather than inflation. The reason is that in the context of this model, assuming an inflationary objective leads to the well-known problem of indeterminacy. The price level would be indeterminate. It is 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 of 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 there is also an output expansion that tends to result in a rise in interest rate. Therefore, whenever $b\phi$ 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 the interest rate.

3.3 Imperfect capital mobility

Until now, we have assumed that capital is perfectly mobile. Frenkel and Rodriguez (1982) argue that the limits to capital mobility may explain why exchange rates adjust more slowly 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 denotes 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 the balance in the current account becomes more important as a determinant of the exchange rate vis-à-vis the parity condition.

This representation is the same as the traditional way models of the 1980s 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 $-\phi(s - p) = \gamma(i - i^* - \dot{s})$. This is the same as our parity condition just by recognizing that $\gamma \equiv 1/\beta$.

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

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 a *decline in the interest rate and undershooting* as a result of a monetary expansion. In the limit, when $\beta \to \infty$, the coefficient of p is positive and equal to 1, in which case there is indeterminacy. Indeed, for all $\beta > (1 - \kappa\phi)/\eta\phi$, the slope of $\dot{s} = 0$ is positive and there is 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. Under imperfect capital mobility, however, we can still have undershooting and a decline in the interest rate. For this we need a large value of β. The monetary expansion will cause a decline in the interest rate and a depreciation of the currency, which will go on depreciating towards the new steady state.

The mechanics of undershooting can be understood by examining (10). The decline in the interest rate may be consistent with an expected depreciation if the risk premium drops more than the decline in the interest rate. This means that the decline in i must be less than the decline in the risk premium, and hence $\dot{s}$ should be positive when there is a monetary expansion, despite the fall in i. The latter effect is due to the initial depreciation that generates an improvement in the current account that reduces the risk premium. From a practical point of view it seems unrealistic that a monetary expansion would cause a decline in the risk premium large enough to offset the arbitrage effects of a reduction in the domestic interest rate.

Although the results of Dornbusch's model —extended to include 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 rather on the stock than on the flows of foreign liabilities. Moreover, perhaps government liabilities are the most relevant factors influencing risk premia.

From the exercises analyzed in this 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 counterintuitive. 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.

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

In this section we present the DNK model —modified to allow for inflation targeting— that will be used to describe the simulation exercises.[5] The model consists of an open economy in which there is a central bank, a fiscal authority (the government), a representative consumer, and monopolistically competitive firms. All goods are tradable. As is standard in this literature, domestic production requires a continuum of differentiated labor inputs that are supplied by home individuals. Time is discrete.

Having described the general setup of the model, we proceed in three steps. First, we outline the main building blocks of the model and its micro-foundations. Second, we derive the main price relationships of the model (inflation rates and exchange rates). Finally, we embed these relationships in an otherwise conventional DNK model.[6]

4.1 Micro-foundations of Demand and Supply

4.1.1 Preferences

The economy has a continuum of measure 1 of consumers-producers indexed by $j \in [0, 1]$, where each consumer-producer has the same intertemporal lifetime utility function

$$\mathrm{E}_t U_t(j) = \mathrm{E}_t \sum_{k=0}^{\infty} \beta^k \left\{ u(C_{t+k}(j)) + h\left(\frac{M_{t+k}(j)}{P_{t+k}}\right) - v(Y_{t+k}(j)) \right\}, \tag{12}$$

where $0 < \beta < 1$ is the discount factor. M and Y are money balances and production of good j, and C_t is a composite consumption index defined by

$$C_t = \left[(1-\gamma)^{\frac{1}{\eta}} \left(C_{H,t}\right)^{\frac{\eta-1}{\eta}} + \gamma^{\frac{1}{\eta}} \left(C_{F,t}\right)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}, \tag{13}$$

[5]This framework builds on previous research by Svensson (1999, 2000) and Galí and Monacelli (2002), all of which focus on the performance of simple policy rules (whether optimal or not) in open economies. See Lane (2001) for a survey on the new open macroeconomics literature that incorporate imperfect competition and nominal rigidities.

[6]See Goodfriend and King (1997) and Clarida, Galí, and Gertler (1999) for a description of the DNK approach.

where $\eta > 0$ is the elasticity of substitution between domestic and foreign goods, and γ is the share of domestic consumption allocated to imported goods. The two consumption subindexes, $C_{H,t}$ and $C_{F,t}$, are symmetric and are defined, as in Dixit and Stiglitz (1977), by

$$C_{H,t} = \left[\int_0^1 C_{H,t}(j)^{\frac{\theta-1}{\theta}} dj \right]^{\frac{\theta}{\theta-1}}; \quad C_{F,t} = \left[\int_0^1 C_{F,t}(j)^{\frac{\theta-1}{\theta}} dj \right]^{\frac{\theta}{\theta-1}}, \tag{14}$$

where $\theta > 1$ will turn out to be the price elasticity of demand faced by each monopolist, $C_{H,t}(j)$ and $C_{F,t}(j)$ are the quantities purchased by home agents of home and foreign goods, respectively.

Each agent produces one differentiated good, and the disutility from production is given by υ.

Consumers can store domestic non-interest bearing money and, as in Cole and Obstfeld (1991) and Galí and Monacelli (2002), these consumers can also hold state-contingent claims. The latter means that *ex-ante* there are complete international financial markets, and thus, there is no need for international portfolio diversification. In equilibrium, it will also mean that transitory shocks do not have permanent consequences, thereby sharply simplifying our analysis. The individual household constraint is given by

$$\begin{aligned} & \int_0^1 \left[P_{H,t}(j) C_{H,t}(j) + P_{F,t} C_{F,t}(j) \right] dj + M_t(j) + \mathrm{E}_t \left[F_{t,t+1} B_{t+1}(j) \right] \qquad (15) \\ = \; & (1-\tau) P_{H,t}(j) Y_{H,t}(j) + M_{t-1}(j) + B_t(j) + TR_t, \end{aligned}$$

where $F_{t,t+1}$ is the stochastic discount factor, B_{t+1} is the payoff in period $t+1$ of the portfolio held at the end of period t, TR_t are lump sum transfers, and τ is a proportional tax on nominal income.

The home commodity demand functions resulting from cost minimization are

$$C_{H,t}(j) = \left[\frac{P_{H,t}(j)}{P_{H,t}} \right]^{-\theta} C_{H,t}; \;\; C_{F,t}(j) = \left[\frac{P_{F,t}(j)}{P_{F,t}} \right]^{-\theta} C_{F,t},$$

where $P_{H,t} \equiv \left[\int_0^1 P_{H,t}(j)^{1-\theta} dj \right]^{\frac{1}{1-\theta}}$ and $P_{F,t} \equiv \left[\int_0^1 P_{F,t}(j)^{1-\theta} dj \right]^{\frac{1}{1-\theta}}$ are the price indexes for domestic and foreign goods, both expressed in the domestic currency.

Using the definition of total consumption (13), we can derive the demand allocation for home and foreign goods

$$C_{H,t} = (1-\gamma) \left[\frac{P_{H,t}}{P_t} \right]^{-\eta} C_t; \; C_{F,t} = \gamma \left[\frac{P_{F,t}}{P_t} \right]^{-\eta} C_t, \tag{16}$$

where $P_t \equiv \left[(1-\gamma)\left(P_{H,t}\right)^{1-\eta} + \gamma\left(P_{F,t}\right)^{1-\eta}\right]^{\frac{1}{1-\eta}}$ is the consumer price index (CPI).

Substituting equation (16) into the budget constraint (15), we can obtain a new expression for the latter in terms of the composite good:

$$\begin{aligned} & P_t C_t + M_t(j) + \mathrm{E}_t\left[F_{t,t+1} B_{t+1}(j)\right] \\ = \quad & (1-\tau) P_{H,t}(j) Y_{H,t}(j) + M_{t-1}(j) + B_t(j) + TR_t. \end{aligned} \tag{17}$$

The home agent's problem is to choose paths for consumption, money, and output of good j. Therefore, the representative consumer chooses her optimal holdings of contingent bonds, $B(j)$, and her money holdings, $M(j)$, to maximize her expected utility (12) subject to the budget constraint (17). It follows that the first order necessary conditions are:

$$\beta \mathrm{E}_t\left[\frac{u_c(C_{t+1})}{u_c(C_t)} \frac{P_t}{P_{t+1}}\right] = \mathrm{E}_t[F_{t,t+1}], \tag{18}$$

$$u_c(C_t) = h_m\left(\frac{M_t}{P_t}\right)\frac{1}{P_t} + \beta \mathrm{E}_t\left\{u_c(C_{t+1})\frac{P_t}{P_{t+1}}\right\}. \tag{19}$$

Equation (18) represents the traditional intertemporal Euler equation for total real consumption, while equation (19) corresponds to the intertemporal Euler equation for money.

The problem is analogous for the rest of the world. However, the crucial assumption here is that the share of goods that are not produced within the economy is insignificant. Thus, the Euler equation for the rest of the world would be:

$$\beta \mathrm{E}_t\left[\frac{u_c^*(C_{t+1})}{u_c^*(C_t^*)} \frac{P_t^*}{P_{t+1}^*} \frac{\mathrm{E}_t}{\mathrm{E}_{t+1}}\right] = \mathrm{E}_t\left[F_{t,t+1}\right]. \tag{20}$$

Combining and iterating equations (18) and (20) we have that

$$u_c(C_t) = \kappa u_c^*(C_t^*) Q_t, \tag{21}$$

where $Q_t = \frac{ES_t P_t^*}{P_t}$ is the real exchange rate and κ is a constant that depends on initial wealth differences. Thus, the complete markets assumption brings equation (21), which associates home consumption to the rest of the world's consumption and a switching factor given by the real exchange rate.[7]

[7]The complete markets assumption has the additional advantage of eliminating foreign asset accumulation or decumulation from the dynamics of the economy. As a result, the steady state is unique, in that consumption is independent of the past history of shocks. We can thus linearize

4.1.2 Technology and Price Setting

The model employs a price-setting process that follows Calvo (1983), in which firms are able to change their prices only with some probability, independently of other firms and the time elapsed since the last adjustment. We assume that producers behave as monopolistic competitors. Each firm faces the following demand function

$$y^d_{H,t}(j) = \left[\frac{p_{H,t}(j)}{P_{H,t}}\right]^{-\theta} C^A_{H,t}, \tag{22}$$

where $C^A_{H,t} = C_{H,t} + C^*_{H,t}$.

Recall that the economy has a continuum of measure 1 of consumers-producers indexed by $j \in [0,1]$, where each consumer-producer has the same expected profit function. It follows that the objective function can be written as

$$\mathrm{E}_t \sum_{k=0}^{\infty} \alpha^k \beta^k \Lambda_{t+k} \left\{ \frac{p_{H,t}(j)}{P_{H,t+k}} \left(\frac{p_{H,t}(j)}{P_{H,t+k}}\right)^{-\theta} C^A_{H,t+j} - \frac{W_{t+k}}{P_{H,t+k}} \frac{V\left[\left(\frac{p_{H,t}(j)}{P_{H,t+k}}\right)^{-\theta} C^A_{H,t+k}\right]}{Z_t} \right\}, \tag{23}$$

where α is the probability that consumers-producers maintain the same price of the previous period, Λ is the marginal utility of home goods, $\frac{V\left[y^d_{H,t}(j)\right]}{Z_t}$ is the input requirement function, Z is an exogenous economy-wide productivity parameter, and hence $\upsilon \equiv V/Z$, and W is the price of the composite input.

The problem of the producers, to be solved in the Appendix, is to choose $p_t(j)$ to maximize equation (23) subject to (22).

4.2 Government

We assume that the government balances its budget each period. Thus, the government budget constraint is given by

$$\tau P_{H,t} Y_{H,t} - TR_t + M_t - M_{t-1} = 0.$$

We restrict our analysis to the case in which $\tau = \frac{1}{1-\theta}$. Here, the government offsets the market power distortion created by monopolistic competition in the market

around that unique steady state. This is not possible in standard models of small open economies. However, the caveat of this assumption is that it prevents current account fluctuations. The mechanism of adjustment to shocks depends exclusively on real exchange rate fluctuations, without changes in net-asset positions. See, the seminal paper by Corsetti and Pesenti (2001).

for differentiated goods. This means that the only distortion in the economy will be price rigidity, and offsetting the effects of that distortion will be the objective of monetary policy.

4.3 Price Relationships

Before moving to the complete log-linearized model, we define the price relationships (in log terms) involved in the model.

Let $p_{H,t}$ and $p_{F,t}$ be the stochastic components of (log) levels of domestic and foreign good prices in period t, respectively. Thus, the (log) Consumer Price Index (CPI) can be defined as

$$p_t = (1-\gamma)p_{H,t} + \gamma p_{F,t}, \tag{24}$$

where γ, a parameter of the utility function, is the share of foreign goods in the CPI. Therefore, the (log) CPI inflation can also be defined as

$$\pi_t = (1-\gamma)\pi_{H,t} + \gamma \pi_{F,t}, \tag{25}$$

where $\pi_{H,t} = p_{H,t} - p_{H,t-1}$ is domestic inflation and $\pi_{F,t} = p_{F,t} - p_{F,t-1}$ denotes foreign inflation. It is worth noting that, depending on the choice of the inflation target (CPI or domestic inflation), π_t and $\pi_{H,t}$ will be measured as deviations from a constant mean, which equals the constant inflation target.

Similarly, the (log) real exchange rate can be defined as

$$q_t \equiv s_t + p_t^* - p_t \Rightarrow q_t = (1-\gamma)(s_t + p_t^* - p_{H,t}), \tag{26}$$

where we have included the key assumption that the rest of the world behaves as a closed economy, i.e. $p_t^* = p_{F,t}^*$. In other words, we are assuming that the consumption of foreign goods by foreigners (that is, of the goods produced by the home economy) is negligible for the rest of the world.[8]

4.4 The Log-Linearized Model

This section presents the complete log-linearized model of this open economy. Additional details are deferred to the Appendix.

Let lower-case variables denote percent deviations from the steady state, and let ratios of capital letters without a time subscript denote steady-state values of the respective ratios. It is then convenient to express the complete log-linearized model

[8] Monacelli (2004) uses the same approximation.

in terms of three blocks of equations: (1) Aggregate Demand, (2) Aggregate Supply, and (3) Monetary Policy Rule and Stochastic Processes.

4.4.1 Aggregate Demand

Aggregate demand in this economy is given by[9]

$$x_t = \mathrm{E}_t[x_{t+1}] - \frac{1}{\sigma} i_t + \phi_\pi \mathrm{E}_t[\pi_{H,t+1}] - \phi_s \left(\mathrm{E}_t[s_{t+1}] - s_t\right) - (1 - \rho_z) z_t, \tag{27}$$

where $\phi_\pi = \left[\frac{1}{\sigma} - \frac{1-\gamma}{\sigma}\left(1 - \frac{\varphi}{1-\gamma}\right)\right]$, $\phi_s = \left[\frac{1}{\sigma} - \frac{1-\gamma}{\sigma}\left(1 - \frac{\varphi}{1-\gamma}\right)\right]$, and $0 \leq \rho_z \leq 1$. Note that $i_t = \frac{1}{\mathrm{E}_t[F_{t,t+1}]}$ is the gross return on a riskless one-period discount bond paying off one unit of domestic currency in $t+1$. The disturbance z_t is the natural level of output that is driven by shocks arising from technologies. Hence, it is interpreted as a productivity shock.

Equation (27) represents a non-traditional IS curve that relates output gap not only to the interest rate, but to expected future output gap and to current and expected future nominal exchange rates as well. A nominal depreciation, and consequently a real depreciation, raises aggregate demand, because it shifts demand from foreign goods to domestic output (foreign prices are given, and any repercussion effects from the home economy to the rest of the world are neglected). It is worth mentioning that the nominal exchange rate appears on the IS curve because we express the aggregate demand in terms of domestic inflation rather than CPI inflation. This is useful not only to decompose overall inflation into the domestic and foreign components but also to model exchange rate flexibility in the monetary policy rule.

4.4.2 Aggregate Supply

Aggregate supply is obtained by log-linearizing the first order condition of the price setting problem.[10] It follows that

$$\pi_{H,t} = \beta \mathrm{E}_t[\pi_{H,t+1}] + \lambda_x x_t + \lambda_q q_t \tag{28}$$

$$\text{or } \pi_{H,t} = \beta \mathrm{E}_t[\pi_{H,t+1}] + \lambda_x x_t + \lambda_q (s_t + p_t^* - p_{H,t}) + u_t, \tag{29}$$

and

[9] See Appendix.

[10] See Appendix.

$$\pi_t = (1-\gamma)\pi_{H,t} + \gamma(s_t - s_{t-1}), \tag{30}$$

where $\lambda_x = \frac{(1-\alpha)(1-\alpha\beta)}{\alpha(1+\xi\theta)}\xi$, $\lambda_q = \lambda_x \frac{\delta}{1-\gamma}$, $\xi > 0$ is the elasticity of V' with respect to Y_t^d, u_t is a cost push shock, and δ is the share of tradable goods in the composite input. The latter implies that the exchange rate component will not enter the aggregate supply function if the composite input is only domestic.

Equation (28) embeds the staggered price setting formulation of Calvo (1983) described earlier, giving rise to the dynamic version of the aggregate supply schedule for domestic goods. Current domestic inflation depends on expected future domestic inflation, current domestic output, and the real exchange rate. The real exchange rate enters the price equation because there are imported inputs, whose importance is measured by δ. This reflects the forward-looking nature of the price setting, due to the implicit costs of changing prices.

Equation (30) defines CPI inflation in terms of domestic inflation and accumulated nominal exchange rate depreciation. Derivation of this equation assumes foreign prices to be constant.

4.4.3 Uncovered Interest Parity Condition

Uncovered interest parity condition (UIP) is given by

$$i_t = i_t^* + \mathrm{E}_t[s_{t+1}] - s_t, \tag{31}$$

which relates the movements of the interest rate differentials to the expected variations in the nominal exchange rate.

4.4.4 Monetary Policy Rules and Stochastic Processes

We assume that the Central Bank manages a short term nominal interest rate according to an open economy variant of the Taylor rule.[11] Specifically, we consider a rule in which the central bank adjusts the current nominal interest rate in response to expected inflation, the current output gap, the current exchange rate, and the lagged interest rate. In general, this kind of rule provides a fairly good description of the variation of short term interest rates.[12]

As shown by Clarida, Galí, and Gertler (1998), the current interest rate typically depends on the interest rate target and the lagged interest rate, i.e., there is a

[11]The model focuses on interest rate policies, while most other papers try to characterize the optimal behavior of the nominal quantity of money, starting with the seminal paper by Obstfeld and Rogoff (1995).

[12]See Clarida, Galí, and Gertler (1998, 2000) and Rotemberg and Woodford (1999).

degree of interest rate smoothing given by ρ_i. The assumption behind this point is that monetary authorities are concerned about interest rate volatility, because it is presumably costly in terms of financial market health and also investment and growth. Thus we have,

$$i_t = (1 - \rho_i)\bar{\imath}_t + \rho_i i_{t-1}, \tag{32}$$

where $\bar{\imath}_t$ is the nominal interest target toward which the central bank gradually adjusts the interest rate, given by

$$\bar{\imath}_t = \chi_\pi \mathrm{E}_t[\pi_{t+k} - \bar{\pi}] + \chi_x x_t + \chi_s s_t, \tag{33}$$

where $\chi_\pi > 1$, $\chi_x \geq 0$, $\chi_s \geq 0$, and $\bar{\pi}$ is the inflation target. It is important to note that the policy rule used by the monetary authority depends on expected future inflation. Higher expected future inflation raises the current nominal interest rate target. Batini and Haldane (1999) also consider this kind of policy rule. They conclude that inflation forecast-based policy rules embody all information useful for predicting future inflation, and can achieve a high degree of output smoothing.

Including the term χ_s in the policy rule helps to reproduce the behavior of nominal exchange rates. Depending on the degree of control that the central bank exercises over the nominal exchange rate – the value of χ_s – this rule will imply the type of exchange regime chosen by the country. If $\chi_s \approx 0$, the central bank does not care about deviations of the nominal exchange rate, i.e., the economy reproduces a flexible exchange rate behavior. On the other hand, if $\chi_s \in (0, \infty)$, the central bank acts in response to the deviation of the nominal exchange rate from its current target or steady-state value. This case would correspond to a managed exchange rate and, in the limit as χ_s goes to infinity, to a fixed exchange rate. Note that exchange rate, in the context of perfect capital mobility, must be managed via changes in the interest rate, and there is no scope for sterilized intervention.

Plugging equation (33) into equation (32), we have that the monetary policy rule is given by[13]

$$i_t = \rho_i i_{t-1} + \upsilon_\pi \mathrm{E}_t[\pi_{t+k} - \bar{\pi}] + \upsilon_x x_t + \upsilon_s s_t, \tag{34}$$

[13] An important consideration is in order about the definition of inflation targeting. Some authors argue, based on McCallum and Nelson (1999) and Batini and Haldane (1999), that inflation targeting is the case in which monetary policy responds to inflation in addition to other variables such as output and real exchange rates. Alternatively, Svensson defines targeting one or several variables means minimizing a loss function that is increasing in the deviation between the target variable(s) and the target level(s). He points out that "the best way to minimize such a loss function is then to respond optimally with the instrument to the determinants of the target variables, that is, the state variables of the economy."

Note that these two definitions are equivalent only if there is a one-to-one relation between the variables in the reaction function and the loss function.

where $v_\pi = (1-\rho_i)\chi_\pi$, $v_x = (1-\rho_i)\chi_x$, and $v_s = (1-\rho_i)\chi_s$.

Finally, equations (35), (36), (37), and (38) describe the evolution of the inflation target, the foreign interest rate, the foreign output, technology, and cost push shocks, respectively.

$$\overline{\pi}_t = \rho_{\overline{\pi}}\overline{\pi}_{t-1} + \varepsilon_t^{\overline{\pi}}, \tag{35}$$

$$i_t^* = \rho_{r^*} i_{t-1}^* + \varepsilon_t^{i^*}, \tag{36}$$

$$z_t = \rho_z z_{t-1} + \varepsilon_t^z, \tag{37}$$

$$u_t = \rho_u u_{t-1} + \varepsilon_t^u, \tag{38}$$

where , $\varepsilon_t^{\overline{\pi}}$, $\varepsilon_t^{i^*}$, ε_t^z, and ε_t^u are i.i.d. shocks distributed with zero mean.

5 Simulation Exercises

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

5.1 Model Parameterization

For the parameters, standard values that appear in the traditional related literature are chosen.

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 $\gamma = 0.7$. 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 (34)— 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 $\chi_s \approx 0$ and for managed exchange rate we use $\chi_s = 2.2$. Finally, the serial correlation parameters for the shocks are set equal to 0.8.

5.2 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 0.8. As stressed by Rotemberg and Woodford (1999), 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, which are discussed after presenting the simulations.

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 persistent 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 on domestic currency. As in the original case, the only possibility to combine a long-term depreciation 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 a real exchange rate depreciation, 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 in the case without foreign exchange intervention. Thus, the reaction of the nominal interest is also more limited if the nominal exchange rate is managed, because the overshooting feature is not present. 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. As with the inflation target shock, the foreign interest rate shock results in an exchange rate that stays persistently above the initial steady state. Given that prices are sticky, the real exchange rate depreciates and, hence, has a marginal 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.

Productivity 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. Similar to the previous cases, the nominal exchange rate also exhibits the overshooting behavior, depreciating on impact, and then staying persistently above the original steady state. 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 dynamic model. In particular, a positive cost push shock has an immediate 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 the first periods. In other words, the nominal exchange rate tends to undershoot its initial steady state. Domestic prices tend to increase relatively more than the nominal exchange rate. This combination together with the reaction of the interest rate has a 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 a deeper negative impact on output.

A persistent monetary expansion, as in the original Dornbusch's paper, leads to overshooting. We have modeled 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. Meanwhile, under cost-push shocks the exchange rate depreciates on impact and then rises again persistently above the steady state (undershooting), at least in the first periods. In the augmented Taylor rule we cannot properly define over- or under-shooting, but certainly the effects 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.[14] In particular, tables 1 and 2 compare the unconditional standard deviations of the variables of the dynamic model considering a fully flexible exchange rate and a managed regime, respectively. The main result is that flexible exchange rates tend to dominate managed exchange rates if the economy is hit by a foreign interest rate, productivity, or cost-push shock, while the reverse is true for an inflation target shock. This confirms the conventional wisdom that flexibility is better in the cases of foreign and real shocks, while pegging is preferable in the case of nominal shocks.

For instance, if we take an inflation target shock, we can see that output volatility is lower in the flexible exchange rate 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.

Table 1: Taylor rule: Unconditional Standard Deviations.

Variable	Inflation Target	Foreign Interest Rate	Productivity	Cost Push
Output	2.13	1.40	0.23	2.74
Domestic Inflation	0.15	0.10	0.01	2.92
Interest Rate	0.09	0.36	0.09	1.22
CPI Inflation	0.40	1.10	0.23	2.00
Nom. Exchange Rate	1.60	2.49	0.62	19.77
Real Exchange Rate	0.24	0.61	0.17	3.84
Real Interest Rate	0.40	1.24	0.22	1.37

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

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

Variable	Inflation Target	Foreign Interest Rate	Productivity	Cost Push
Output	0.73	1.68	0.95	11.24
Domestic Inflation	0.04	0.07	0.04	1.96
Interest Rate	0.06	0.57	0.04	0.34
CPI Inflation	0.15	0.48	0.09	0.84
Nom. Exchange Rate	0.38	0.85	0.20	2.61
Real Exchange Rate	0.07	0.33	0.11	2.66
Real Interest Rate	0.15	0.88	0.08	0.63

6 Concluding Remarks

In this paper we have outlined Dornbusch's overshooting model in a new Keynesian dynamic general equilibrium model of a small open economy in which inflation targeting plays a key role for monetary policy. In this way we can verify whether the main results still hold in a general equilibrium model with microeconomic foundations, which is the main criticism against Dornbusch's original model. Indeed, we find that persistent monetary expansions, as in the original overshooting model, entail exchange rate overshooting.

Also, we argue that, most likely, exchange rates are subject to many shocks that make difficult the identification of the pure effect of permanent monetary shocks. One potential explanation for the lack of empirical support for the original model could be that undershooting dominates overshooting. However, in the basic theoretical framework, the conditions to generate undershooting are rather artificial (e.g., the interest rate rising as a result of a monetary expansion).

Although this model could generate some realistic correlations, the volatility of exchange rates is still small with respect to the volatility of prices. This is a traditional problem with calibrated general equilibrium models in their ability to replicate asset price volatility. One possible way to reduce inflation volatility with respect to exchange rate volatility is to add more persistence in the inflation process, and some inertia in the Phillips curve. Alternatively, a more promising avenue would be to consider incomplete pass-through from exchange rate to the price of tradables, since in our simulations there is low volatility of non-tradable inflation, and what drives the volatility of inflation is the impact of exchange rates on tradable inflation. Overall, however, these exercises show that although overshooting may be the result of a monetary policy shock, exchange rate volatility must be dominated by other disturbances.

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 policymakers do in reality. Fear of floating is more related to sudden and sharp changes in the exchange rate rather than targeting a specific level.

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A Model Derivation

A.1 Aggregate Demand

For all differentiated goods, market clearing implies

$$Y_t(j) = C_{H,t}(j) + C^*_{H,t}(j).$$

$$= \left[\frac{P_{H,t}(j)}{P_{H,t}}\right]^{-\theta} (1-\gamma) \left[\frac{P_{H,t}}{P_t}\right]^{-\eta} C_t + \left[\frac{P_{H,t}(j)}{P_{H,t}}\right]^{-\theta} \gamma^* \left[\frac{P_{H,t}}{S_t P^*_t}\right]^{-\eta} C^*_t$$

From equation (21) we have

$$= \left[\frac{P_{H,t}(j)}{P_{H,t}}\right]^{-\theta} \kappa C^*_t \left[(1-\gamma) \left[\frac{P_{H,t}}{P_t}\right]^{-\eta} Q_t^{1/\sigma} + \gamma^* \left[\frac{P_{H,t}}{S_t P^*_t}\right]^{-\eta}\right]$$

Plugging the previous equation into the aggregate domestic output defined as $Y_t \equiv \int_0^1 Y_t(j)dj$, we get

$$Y_t = \kappa C^*_t Q_t^{1/(1-\gamma)} \left[(1-\gamma) Q_t^{1/\sigma - \eta} + \gamma\right]$$

Taking a first order approximation

$$y_t = y^*_t + \frac{\varphi}{\sigma(1-\gamma)} q_t \tag{A.1}$$

where $\varphi = [1 + \gamma(2-\gamma)(\sigma\eta - 1)]$and $y^*_t = c^*_t$.

Combining the previous equation with equation (21) we have

$$c_t = \left(\frac{1-\gamma}{\varphi}\right) y_t + \left(1 - \frac{1-\gamma}{\varphi}\right) y^*_t \tag{A.2}$$

Then, combining (A.1) and (A.2) we obtain an equation that relates domestic consumption with domestic output and the real exchange rate

$$c_t = y_t + \left(1 - \frac{\varphi}{1-\gamma}\right) \frac{1}{\sigma} q_t$$

Finally, assuming that $u(C) = \frac{C^{1-\sigma}}{1-\sigma}$, and using the log-linearization version of the Euler equation (18), we obtain the following expression:

$$y_t = \mathrm{E}_t[y_{t+1}] - \frac{1}{\sigma}\left(i_t - \mathrm{E}_t[\pi_{t+1}]\right) + \frac{1}{\sigma}\left(1 - \frac{\varphi}{1-\gamma}\right)\left(\mathrm{E}_t[q_{t+1}] - q_t\right).$$

In terms of the output gap x_t, we get the expression (27) in the main text

$$x_t = \mathrm{E}_t[x_{t+1}] - \frac{1}{\sigma}\left(i_t - \mathrm{E}_t[\pi_{t+1}]\right) + \frac{1}{\sigma}\left(1 - \frac{\varphi}{1-\gamma}\right)\left(\mathrm{E}_t[q_{t+1}] - q_t\right) - (1-\rho_z)\, z_t.$$

or using the definition of $\pi_t = \pi_{H,t} + s_t - s_{t-1}$ and $q_t = (1-\gamma)\,(s_t - p_{H,t})$, we have

$$\begin{aligned}
x_t \;&=\; \mathrm{E}_t[x_{t+1}] - \frac{1}{\sigma}\left(i_t - \mathrm{E}_t[\pi_{H,t+1} + s_{t+1} - s_t]\right) + \frac{1-\gamma}{\sigma}\left(1 - \frac{\varphi}{1-\gamma}\right)(\mathrm{E}_t[s_{t+1} \\
&\quad -p_{H,t+1}] - s_t + p_{H,t}) - (1-\rho_z)\, z_t. \\
&=\; \mathrm{E}_t[x_{t+1}] - \frac{1}{\sigma} i_t + \frac{1}{\sigma}\mathrm{E}_t[\pi_{H,t+1}] - \frac{1}{\sigma}\left(\mathrm{E}_t[s_{t+1}] - s_t\right) + \frac{1-\gamma}{\sigma}\left(1 - \frac{\varphi}{1-\gamma}\right)(\mathrm{E}_t[s_{t+1}] - \\
&\quad s_t) - \frac{1-\gamma}{\sigma}\left(1 - \frac{\varphi}{1-\gamma}\right)\mathrm{E}_t[\pi_{H,t+1}] - (1-\rho_z)\, z_t. \\
&=\; \mathrm{E}_t[x_{t+1}] - \frac{1}{\sigma} i_t + \phi_\pi \mathrm{E}_t[\pi_{H,t+1}] - \phi_s\left(\mathrm{E}_t[s_{t+1}] - s_t\right) - (1-\rho_z)\, z_t.
\end{aligned}$$

where $\phi_\pi = \left[\frac{1}{\sigma} - \frac{1-\gamma}{\sigma}\left(1 - \frac{\varphi}{1-\gamma}\right)\right]$, $\phi_s = \left[\frac{1}{\sigma} - \frac{1-\gamma}{\sigma}\left(1 - \frac{\varphi}{1-\gamma}\right)\right]$, and $0 \le \rho_z \le 1$.

A.2 Aggregate Supply

The FONC of the firm is:

$$\mathrm{E}_t\left\{\sum_{k=0}^{\infty}\alpha^k\beta^k\Lambda_{t+k}\left[\frac{p_{H,t}(j)}{P_{H,t+k}} - \frac{\theta}{\theta-1}\frac{W_{t+k}}{P_{H,t+k}}\frac{V'\left[\left(\frac{p_{H,t}(j)}{P_{H,t+k}}\right)^{-\theta} Y^d_{t+k}\right]}{\widetilde{Z}_t}\right]\left(\frac{p_{H,t}(j)}{P_{H,t+k}}\right)^{-\theta} Y^d_{t+k}\right\} = 0.$$

Define $G_t \equiv \frac{p_{H,t}(j)}{P_{H,t}}$, $\Pi_{H,t} \equiv \frac{P_{H,t}}{P_{H,t-1}}$ and $\zeta \equiv \frac{\theta}{\theta-1}$, then

$$\mathrm{E}_t\left\{\sum_{k=0}^{\infty}\alpha^k\beta^k\Lambda_{t+k}\left[\frac{G_t}{\prod\limits_{s=1}^{k}\Pi_{H,t+s}}-\zeta\frac{W_{t+k}}{P_{H,t+k}}\frac{V'\left[\left(\frac{G_t}{\prod_{s=1}^{k}\Pi_{H,t+s}}\right)^{-\theta}Y^d_{t+k}\right]}{\widetilde{Z}_t}\right]\left(\frac{G_t}{\prod\limits_{s=1}^{k}\Pi_{H,t+s}}\right)^{-\theta}Y^d_{t+k}\right\}=0.$$

In equilibrium, each consumer-producer that chooses a new price in period t will choose the same new price, and the same level of output. Then the (aggregate) price of domestic goods will obey

$$p_{H,t}=\left[\alpha p_{H,t-1}+(1-\alpha)p_{H,t}(j)\right]^{\frac{1}{1-\theta}}.$$

Therefore,

$$\Pi_{H,t}=\alpha^{\frac{1}{1-\theta}}\left[1-(1-\alpha)G_t^{1-\theta}\right]^{\frac{1}{\theta-1}}.$$

Log-linearizing around the steady state. We allow bounded fluctuations in ($C^A_{H,t+k}$, $\Pi_{H,t}$, G_t, Λ_t, and $\frac{W_t}{P_{H,t}}$) around a steady state (y^d, 1, 1, Λ, and 1). Thus,

$$\begin{aligned}
v'_t &= \xi y^d_t,\\
w_t &= (1-\delta)p_{H,t}+\delta p_{F,t},\\
\pi_{H,t} &= \frac{1}{(\theta-1)}\frac{-(1-\alpha)}{(1-(1-\alpha))}(1-\theta)g_t=\frac{1-\alpha}{\alpha}g_t,
\end{aligned}$$

where $\xi>0$ is the elasticity of V' with respect to Y^d_t , $0\leq\delta\leq1$ is the share of tradable goods in the composite input.

$$\mathrm{E}_t\left\{\sum_{k=0}^{\infty}\alpha^k\beta^k\left[g_t-\sum_{s=1}^{k}\pi_{H,t+s}-w_{t+k}+p_{H,t+k}-\xi\left(y^d_{t+k}-\theta\left(g_t-\sum_{s=1}^{k}\pi_{H,t+s}\right)\right)+\widetilde{z}_{t+k}\right]\right\}=0,$$

$$\mathrm{E}_t\left\{\sum_{k=0}^{\infty}\alpha^k\beta^k\left[(1+\xi\theta)\left(g_t-\sum_{s=1}^{k}\pi_{H,t+s}\right)-\xi y^d_{t+k}-\frac{\delta}{1-\gamma}q_{t+k}+\widetilde{z}_{t+k}\right]\right\}=0.$$

However, $\sum\limits_{k=0}^{\infty}\alpha^k\beta^k\sum\limits_{s=1}^{k}\pi_{H,t+s} = \sum\limits_{s=1}^{\infty}\pi_{H,t+s}\sum\limits_{k=s}^{\infty}\alpha^k\beta^k = \sum\limits_{s=1}^{\infty}\pi_{H,t+s}\frac{\alpha^s\beta^s}{1-\alpha\beta}$, and this is equal to $\frac{1}{1-\alpha\beta}\sum\limits_{k=1}^{\infty}\alpha^k\beta^k\pi_{H,t+k}$.

Then, we can rewrite

$$\mathrm{E}_t\left\{\frac{1+\xi\theta}{1-\alpha\beta}g_t - \frac{1+\xi\theta}{1-\alpha\beta}\sum_{k=1}^{\infty}\alpha^k\beta^k\pi_{H,t+k} - \sum_{k=0}^{\infty}\alpha^k\beta^k\left[\xi y_{t+k}^d + \frac{\delta}{1-\gamma}q_{t+k} - \widetilde{z}_{t+k}\right]\right\} = 0.$$

Thus,

$$g_t = \mathrm{E}_t\left\{\sum_{k=1}^{\infty}\alpha^k\beta^k\pi_{H,t+s} + \frac{1-\alpha\beta}{1+\xi\theta}\sum_{k=0}^{\infty}\alpha^k\beta^k\left[\xi y_{t+k}^d + \frac{\delta}{1-\gamma}q_{t+k} - \widetilde{z}_{t+k}\right]\right\},$$

$$g_t = \mathrm{E}_t\left\{\alpha\beta\pi_{H,t+1} + \frac{1-\alpha\beta}{1+\xi\theta}\left[\xi y_{t+k}^d + \frac{\delta}{1-\gamma}q_{t+k} - \widetilde{z}_{t+k}\right]\right\} + \alpha\beta\mathrm{E}_t\left[g_{t+1}\right],$$

but $\pi_{H,t} = \frac{1-\alpha}{\alpha}g_t$, then

$$\frac{\alpha}{1-\alpha}\pi_{H,t} = \mathrm{E}_t\left\{\alpha\beta\pi_{H,t+1} + \frac{1-\alpha\beta}{1+\xi\theta}\left[\xi y_t^d + \frac{\delta}{1-\gamma}q_{t+k} - \widetilde{z}_{t+k}\right]\right\} + \alpha\beta\frac{\alpha}{1-\alpha}\mathrm{E}_t\left[\pi_{H,t+1}\right],$$

where we let $\widetilde{z}_t = \xi z_t$ and hence the output gap is defined as $x_t = y_t^d - z_t$. Thus,

$$\pi_{H,t} = \beta\mathrm{E}_t\left[\pi_{H,t+1}\right] + \lambda_x x_t + \lambda_q q_t,$$

or recalling that $q_t = s_t + p_t^* - p_{H,t}$, we get an expression for the aggregate supply (equation (28) in the main text)

$$\pi_{H,t} = \beta\mathrm{E}_t\left[\pi_{H,t+1}\right] + \lambda_x x_t + \lambda_q(s_t + p_t^* - p_{H,t}),$$

where $\lambda_x = \frac{(1-\alpha)(1-\alpha\beta)}{\alpha(1+\xi\theta)}\xi$, and $\lambda_q = \frac{(1-\alpha)(1-\alpha\beta)}{\alpha(1+\xi\theta)}\frac{\delta}{1-\gamma}$.

B Model Solution

The dynamic system is given by equations (27), (28), (31), (34), 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:

$$E_t[k_{t+1}] = Ak_t + Bv_t, \tag{A.3}$$

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 5 by 5 matrix of coefficients, B is a 5 by 4 matrix of coefficients, and v_t is the vector of shocks.

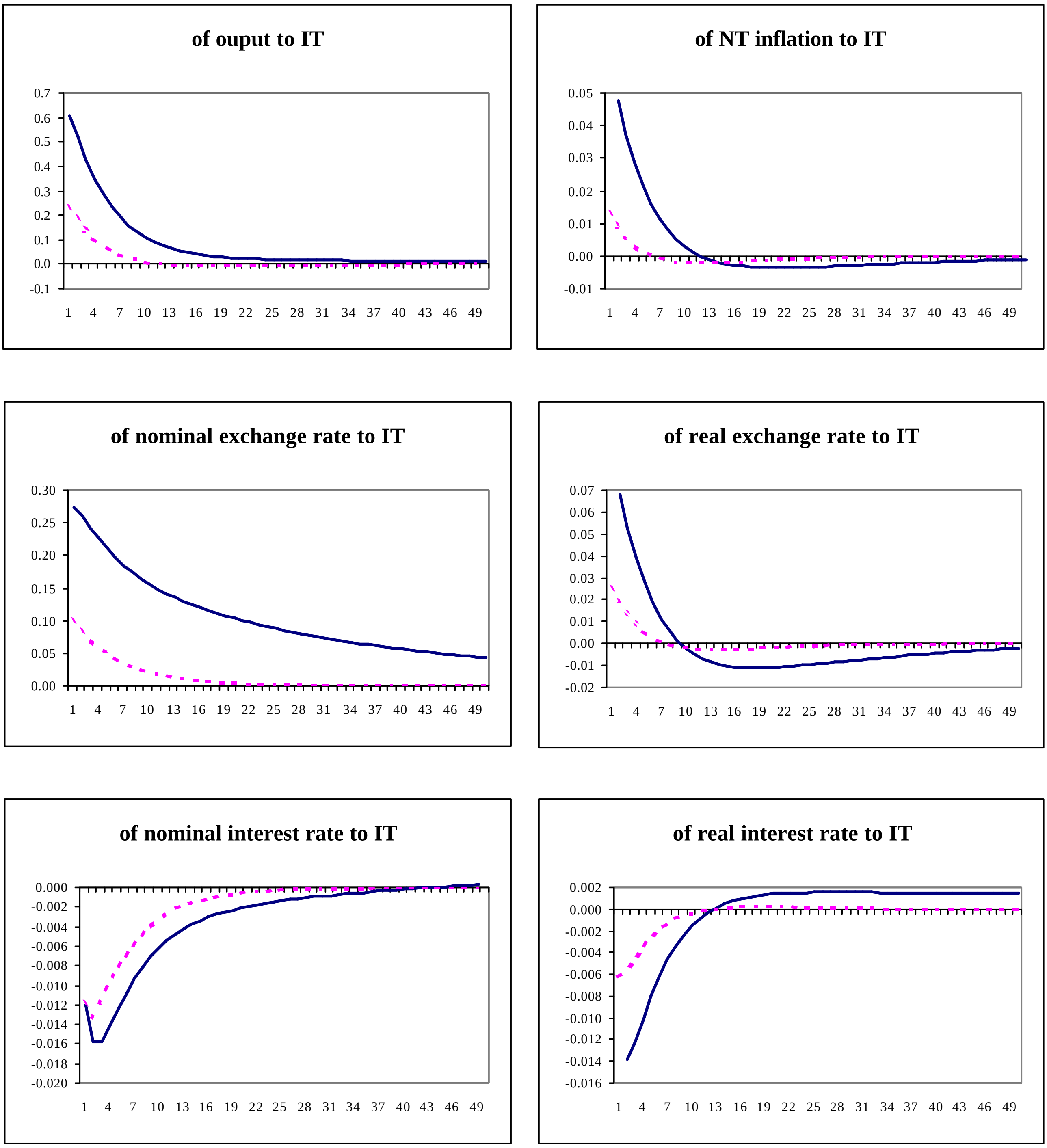
The dynamic system has two predetermined variables: i_{t-1} and p_{t-1}^{NT} , and three nonpredetermined variables: x_t^{NT}, π_t^{NT}, and s_t. Thus, as shown in Blanchard and Kahn (1980), if the number of eigenvalues of A outside the unit circle is equal to the number of nonpredetermined variables —in our case, three— then there exists a unique rational expectations solution to system (A.3).

The strategy is to transform the model into 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 the matrix of eigenvectors, respectively. Thus, we can rewrite system (A.3) as

$$E_t \begin{pmatrix} u_{t+1} \\ z_{t+1} \end{pmatrix} = \begin{pmatrix} J_u & 0 \\ 0 & J_z \end{pmatrix} \begin{pmatrix} u_t \\ z_t \end{pmatrix}. \tag{A.4}$$

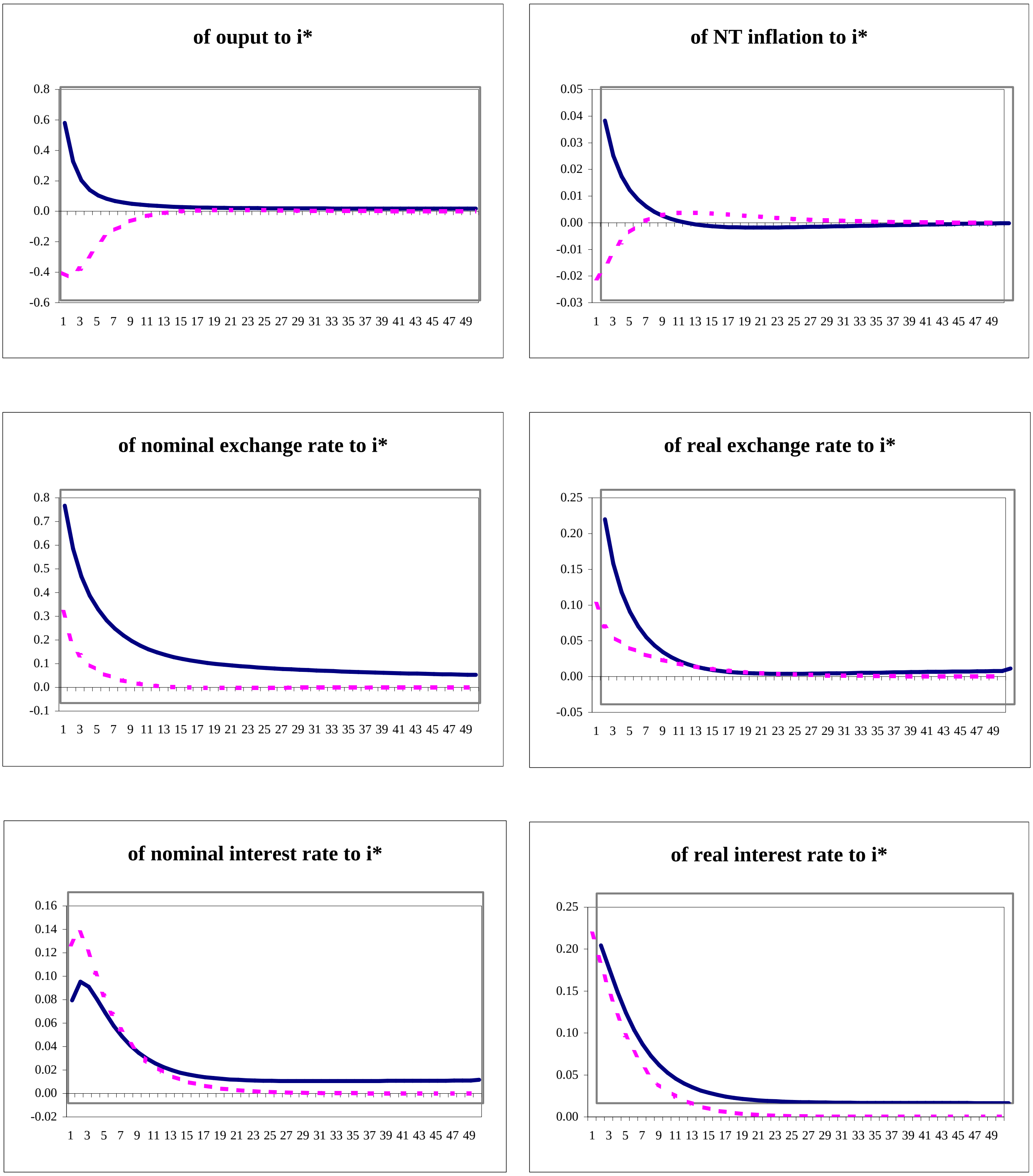
The canonical system requires that we set $u_t = 0$, $\forall t$, to rule out explosive solutions. If the number of eigenvalues outside the unit circle is equal to the number of nonpredetermined variables, then the appropriate normalization choice is $z_t = \begin{pmatrix} i_{t-1} \\ p_{t-1}^{NT} \end{pmatrix}$. 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, the real exchange rate and the interest rate converge towards their steady states.

Figure 4. Impulse Responses: Inflation Target Shock



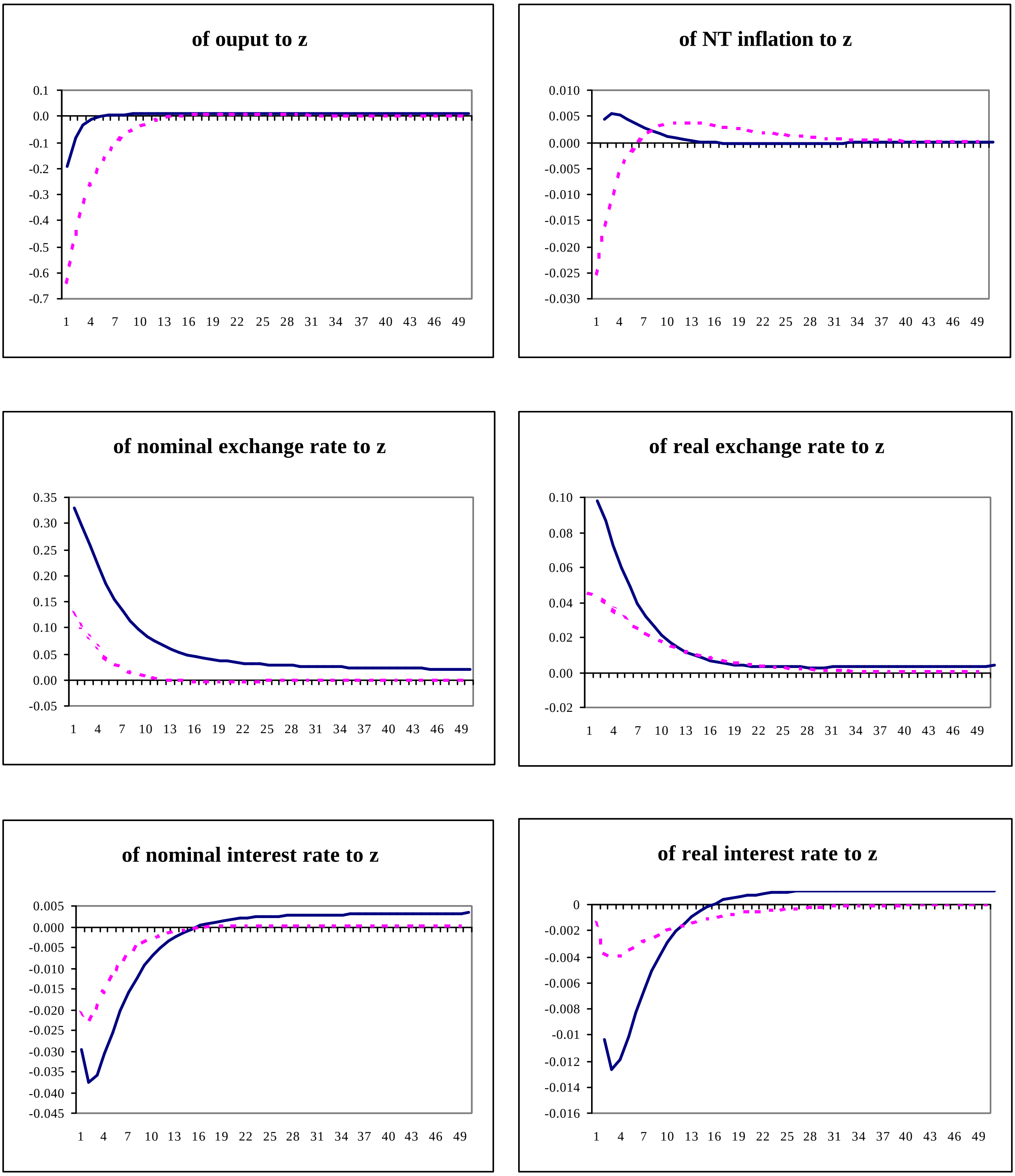
Note: The solid line corresponds to a flexible exchange rate and the dashed line to a managed exchange rate.

Figure 5. Impulse Responses: Foreign Interest Rate Shock



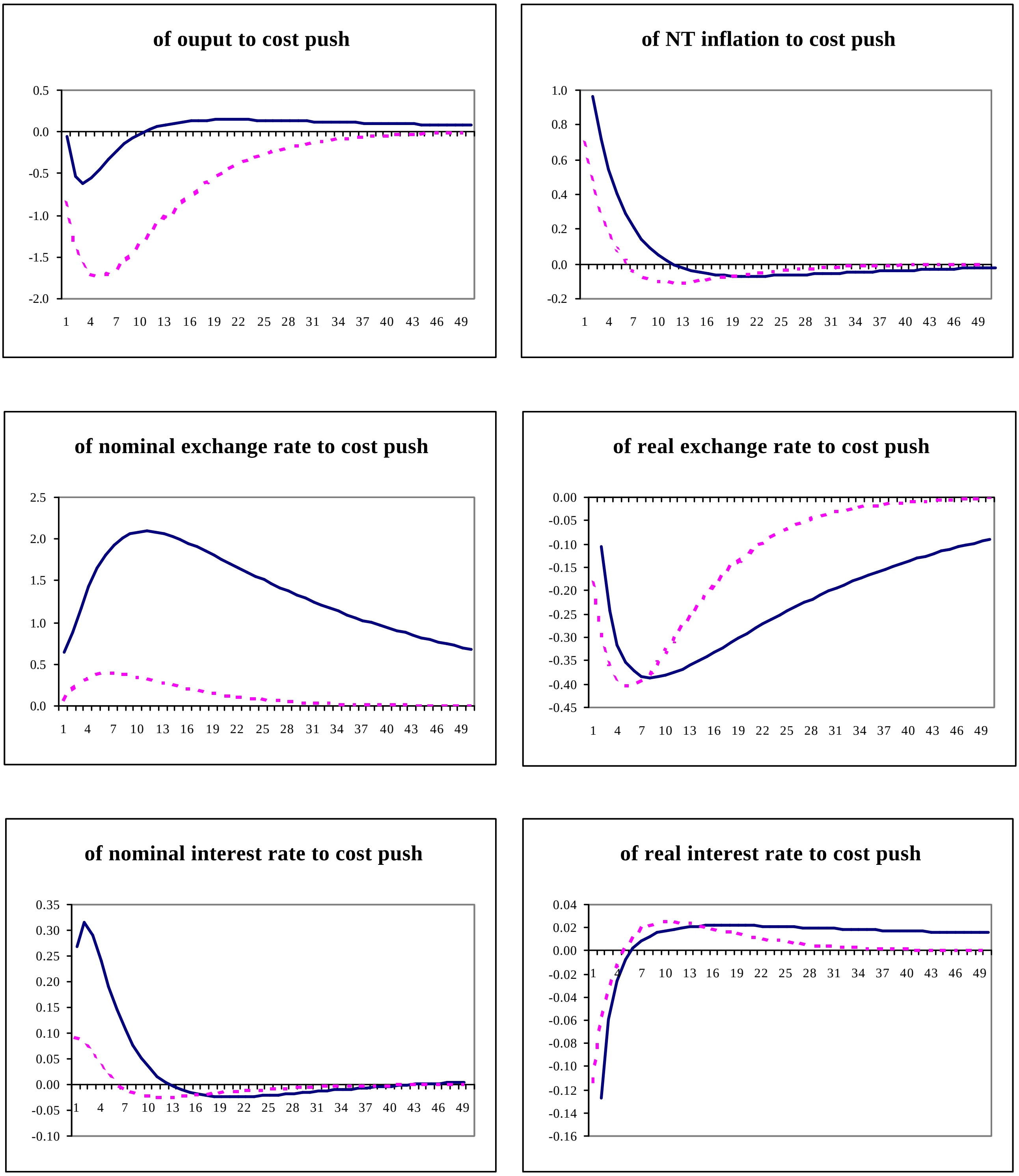
Note: The solid line corresponds to a flexible exchange rate and the dashed line to a managed exchange rate.

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.

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