“State-Dependent Nominal Rigidities & Disinflation Programs
in Small Open Economies”

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October 27, 2004

(Job Market Paper)

**Abstract**

Empirical regularities from high-inflation economies, especially in Latin America, suggest that exchange rate-based (ERB) disinflations and money-based (MB) disinflations induce sharply different dynamics in consumption and GDP. I study the role of nominal rigidities to explain business cycle fluctuations associated to ERB and MB disinflations within a single framework. By building on Calvo's (1983) pricing theory, this paper introduces elements of state-dependent pricing at the firm level into an otherwise standard small open economy model. This new feature allows for endogenous variations in the aggregate degree of nominal rigidities. The model contains as a special case a time-dependent pricing model discussed in the literature. Nonlinear simulations show that the model with state-dependent nominal rigidities generates a dynamic behavior that is more consistent with the empirical evidence, compared to the model with time-dependent pricing.

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# 1 Introduction

Empirical regularities from high-inflation economies, especially in Latin America, suggest that exchange rate-based (ERB) disinflation programs and money-based (MB) disinflation programs induce different dynamics. Such differences are sharper in GDP and consumption. ERB disinflations are characterized by an initial sustained boom in real activity followed by a later recession, whereas MB programs are accompanied by an initial short-lived recession followed by a recovery (Calvo and Végh [1999]).

In models with nominal rigidities, the gradual response of nominal prices to monetary policies creates trade-offs between inflation and output that are summarized by the Phillips curve. Thus, models with nominal rigidities predict inflation-output trade-offs consistent with the initial dynamics of MB disinflation programs. However, by the same token, they are less successful in explaining the initial expansionary phase of ERB disinflations.

In the literature of ERB disinflations it is often the case that inflation acts as a distortionary tax on the relative price of consumption and leisure, then a disinflation program that eliminates such distortion can generate an initial expansionary impulse in consumption. However, in economies with nominal rigidities as those in Calvo, Celasun and Kumhof (2003), Rebelo and Végh (1995) or Uribe (1999), such initial expansionary impulse is ameliorated or eliminated by the effects of the Phillips curve (Rebelo and Végh [1995]). Moreover, in models with flexible prices the inflation-output trade-offs consistent with the initial dynamics of MB disinflations are not present.

The main contribution of this paper is to analyze the role of nominal rigidities to explain the dynamics induced by credible and noncredible ERB and MB disinflation programs within a single framework. The model extends Calvo (1983) time-dependent pricing to introduce elements of state-dependent pricing at the firm level into an otherwise standard small open economy model.

Elements of state-dependent pricing allow for endogenous variations in the degree of nominal rigidities. That is, when faced with large monetary shocks, firms may find optimal to revise their pricing policies more often to accommodate the new state of the economy. In contrast, in models with time-dependent pricing—as those mentioned above—the average frequency at which nominal prices incorporate changes in the state of the economy is constant and exogenous.

As in Calvo (1983) pricing, the model assumes that firms change their pricing policies infrequently, only if they receive a random signal with constant probability. However, different from time-dependent models, firms can choose a higher probability of pricing-plan revisions as part of their optimal pricing plan. Price-setters must pay a cost to benefit from faster pricing-plan revisions. Following Dotsey, King and Wolman (1999), this cost is random. A firm chooses a higher probability of pricing-plan revisions if the cost of doing so is compensated by the change in the value of the firm.

The combination of state-dependent and time-dependent features in the firm's pricing is consistent with economies in which the main cost of changing pricing policies is the cost of learning the state of the economy. As argued by Woodford (2004, Ch. 3) or Blanchard and Fisher (2000, Ch. 8), when the cost of learning the state of the economy is the main cost in pricing, firms must set the date of pricing revisions in calendar time. The model shares such characteristic with time-dependent models. However, the new feature in firm's pricing shows that when firms face large monetary shocks, they may have a strong incentive to adjust pricing policies more often. That endogenizes the aggregate degree of nominal rigidities.

The pricing scheme of the model contains as a special case the time-dependent pricing discussed in Calvo, Celasun and Kumhof (2003) for an open economy or in Cespedes, Kumhof and Parrado (2003) for a closed economy. In policy experiments, I use such special case of the model to isolate the effects of state-dependent pricing.

I study the dynamics of key macroeconomic variables under three disinflation scenarios. The first natural experiment is a permanent and credible disinflation program, however as pointed out by Calvo and Végh (1999), a common characteristic of stabilization programs is imperfect credibility. In the second experiment, as in Calvo (1986), lack of credibility takes the form of a temporary program that lasts for $\tau$ quarters, thereafter the program is abandoned. The third experiment introduces uncertainty. As in Mendoza and Uribe (1997) or Uribe (2002), in the third experiment agents attach probabilities to the abandonment of the disinflation program.

Nonlinear simulations show that in a temporary ERB disinflation program lasting twelve quarters, the model with state-dependent nominal rigidities predicts that, as long as the program is in place, the economy faces a gradually lower degree of nominal rigidities. That in turn, gives room for a sustained expansion in the consumption of tradables—i.e., the sector with nominal rigidities,—followed by a later recession. The boom reaches its peak eight quarters after the implementation of the program. In contrast, in the model's special case of constant nominal rigidities, counterfactually, the recession sets forth immediately after the beginning of the program.

The initial equilibrium path of other key macroeconomic variables is in accordance with observed ERB disinflation episodes. Namely, a gradual fall in inflation, an initial appreciation of the real exchange rate and a boom-recession cycle in the tradable sector.

At the microeconomic level, when the ERB program is perceived as imperfectly credible, firms are willing to spend between five and six percent of their profits to implement more frequent pricing-plan revisions. Such incentive lasts for almost the entire duration of the program. That figures agree with firm level evidence on the cost of pricing activities presented in Zbaraki et al. (2003).

The qualitative properties of the model with state-dependent nominal rigidities and its special case of constant nominal rigidities found for temporary ERB programs also hold in ERB programs of uncertain duration. Moreover, they are robust to alternative calibrations.

On the other hand, in temporary MB disinflations or MB programs with uncertain duration, the model with state-dependent nominal rigidities and its special case, they both predict an initial short-lived recession in nontradables. Moreover, the transition dynamics of both models are qualitative similar.

The rest of the paper is organized as follows. Section 2 presents the model for a small open economy, in particular, subsection 2.2 presents the pricing problem of the firms in the nontradable sector. Section 3 discusses the dynamics of the three stabilization programs studied, including a subsection with sensitivity analysis. Section 4 presents some concluding remarks.

# 2 The Small Open Economy

The small, open economy is populated by a representative household, a continuum of monopolistic competitive firms indexed by $z \in [0, 1]$, a fiscal authority and a monetary authority. For ease of the exposition assume that all agents in the economy have perfect-foresight. I will introduce uncertainty in the subsection 3.4.

Assume that the law of one price holds for internationally tradable goods. This is, $P_t^T = \mathscr{E}_t P_t^{T*}$ in any period $t = 0, 1, 2 \ldots$, where $P_t^T$ and $P_t^{T*}$ denote the nominal price of tradables in the domestic and foreign economy respectively, and $\mathscr{E}_t$ is the nominal exchange rate. Moreover, normalizing the foreign price of tradables to one, the law of one price implies $P_t^T = \mathscr{E}_t$.

The nominal price index of nontradables is $P_t^N$ and $\pi_t \equiv P_t^N / P_{t-1}^N$ is the gross inflation rate of nontradable goods. I define the real exchange rate, $e_t$, as the relative price of tradable goods in terms of nontradables, that is, $e_t = \mathscr{E}_t / P_t^N$. The economy can freely borrow from or lend to the rest of the world, then an uncovered interest parity holds. This is, the domestic nominal interest rate, $i_t$, satisfies

$$1 + i_t = (1 + r)\varepsilon_{t+1}\,, \tag{1}$$

where $r > 0$ is the real international interest rate and $\varepsilon_t \equiv \mathscr{E}_t / \mathscr{E}_{t-1}$ is the gross depreciation rate of the nominal exchange rate.

## 2.1 The Household

The representative household derives utility from leisure and from consumption of a basket of goods containing a homogeneous tradable good $C_t^T$ and a variety of heterogeneous nontradable goods $c_t^N(z)$, where $z$ corresponds to the index of the producing firm. The household's period utility function is

$$U(C_t,\, N_t) \equiv \frac{1}{1-\Gamma}\left(C_t - \varphi C_{t-1}\right)^{1-\Gamma} + \frac{\kappa}{1-\zeta}\left(1 - n_t\right)^{1-\zeta}\,, \tag{2}$$

where $\Gamma > 0$,$\zeta > 0$,$\varphi \in [0,1)$ and $\kappa > 0$ are parameters shaping the household's preferences. $n_t$ is time allocated to work, with the total endowment of time per period normalized to one, and $C_t$ is a composite basket of tradable and nontradable goods. Note that, as in Uribe (2002), preferences allow for non-separability over time in consumption,[1] however $\varphi = 0$ corresponds to the more conventional case of time separability in consumption.

[1] Uribe (2002) shows that for a small open economy with flexible prices, non-separability over time in consumption can help to rationalize stylized facts associated to exchange-rate-based disinflations.

The composite basket of tradable and nontradable goods is

$$C_t \equiv \left(C_t^T\right)^{\gamma} \left(C_t^N\right)^{1-\gamma}, \tag{3}$$

where $\gamma \in (0,1)$ and $C_t^N \equiv \left[\int_0^1 \left[c_t^N(z)\right]^{(\theta-1)/\theta} \mathrm{d}z\right]^{\theta/(\theta-1)}$ with $\theta > 1$, is the Dixit-Stiglitz aggregator of consumption over varieties of nontradable goods $c_t^N(z)$.

Households hold internationally traded bonds denominated in units of tradable goods, $b_t$, which yield a real interest rate $r$. The sources of funds in period $t$ include: the principal and the return of bonds purchased at $t-1$, $b_{t-1}(1+r)$, an endowment of tradable goods $Y_t^T = Y^T$, identical lump-sum transfers in terms of tradables, $a_t$, remunerations from labor at a nominal wage rate $W_t$, and lump-sum transfers equal to the aggregate firms' nominal profits, denoted by $\Delta_t$. The budget constraint in terms of tradables is

$$\frac{W_t n_t}{\mathscr{E}_t} + Y^T + a_t + \frac{\Delta_t}{\mathscr{E}_t} + \frac{M_{t-1}}{\mathscr{E}_t} + b_{t-1}(1+r) \geq \left(C_t^T + \frac{\int_0^1 p_t^N(z) c_T^N(z) \mathrm{d}z}{\mathscr{E}_t}\right)(1+s(u_t)) + b_t + \frac{M_t}{\mathscr{E}_t}.$$

The uses of funds consist of consumption of the homogeneous tradable good $C_t^T$, consumption of nontradable goods $c_t^N(z)$ with nominal price $p_t^N(z)$ for $z \in [0,1]$, transaction costs proportional to consumption expenditure $s(\cdot)$, real bonds in terms of tradables purchased at $t$, $b_t$, and money balances $M_t$ carried to $t+1$.

Following Kimbrough (1986), purchases of goods are subject to transaction costs which are increasing in money velocity $u_t$. The transaction costs technology is

$$s(\cdot) \equiv \frac{K}{\varsigma - 1} (u_t)^{\varsigma - 1}, \tag{4}$$

where $K > 0$ and $\varsigma > 1$. In equation 4, money velocity is defined by

$$u_t \equiv \frac{C_t^T + C_t^N / e_t}{m_t}, \tag{5}$$

where $m_t \equiv M_t / \mathscr{E}_t$.

Imposing the no Ponzi game condition, $\lim_{t\to\infty} \frac{m_t + b_t}{(1+r)^t} \geq 0$, and using the uncovered interest parity (1) we can rewrite the budget constraint as

$$\frac{m_{-1}}{\varepsilon_0} + b_{-1}(1+r) \geq \sum_{t=0}^{\infty} \left(\frac{1}{1+r}\right)^t \left\{ \left[ C_t^T + \frac{\int_0^1 p_t^N(z) c_t^N(z) \mathrm{d}z}{\mathscr{E}_t} \right] (1 + s(u_t)) + \frac{i_t m_t}{1+i_t} - \frac{W_t n_t}{\mathscr{E}_t} - Y^T - a_t - \frac{\Delta_t}{\mathscr{E}_t} \right\}. \tag{6}$$

The representative household chooses $C_t$, $C_t^T$, $C_t^N$, $c_t^N(z)$ $\forall z$, $n_t$, $m_t$ and $u_t$ for $t = 0, 1, 2 \ldots$, to maximize

$$\sum_{t=0}^{\infty} \beta^t U\big(C_t, n_t\big) \tag{7}$$

subject to the consumption aggregator (3), the transaction costs technology (4), the money velocity (5) and the budget constraint (6).

Expenditure minimization yields the demand for nontradable goods:

$$c_t^N(z) = \left(\frac{p_t^N(z)}{P_t^N}\right)^{-\theta} C_t^N, \tag{8}$$

where $P_t^N$ is the utility-based price index defined by $P_t^N \equiv \left[\int_0^1 \left[p_t^N(z)\right]^{1-\theta} \mathrm{d}z\right]^{\frac{1}{1-\theta}}$.

Let $\chi$ denote the time-invariant Lagrange multiplier associated to the budget constraint and assume $\beta = (1+r)^{-1}$ to avoid trends in real variables. The first-order conditions for $C_t^T$ and $C_t^N$ imply:

$$\gamma\left[\left(C_t-\varphi C_{t-1}\right)^{-\Gamma}-\beta\varphi\left(C_{t+1}-\varphi C_t\right)^{-\Gamma}\right]\left(\frac{C_t^N}{C_t^T}\right)^{1-\gamma}=\chi\left[1+s(u_t)+u_t s_u(u_t)\right] \quad (9)$$

and

$$\frac{C_t^N}{C_t^T}=\frac{1-\gamma}{\gamma}e_t, \quad (10)$$

where $s_u(\cdot)$ is the derivative of $s(\cdot)$ with respect to $u_t$.

The first-order condition with respect to real money balances yields $(u_t)^2 s_u(u_t) = i_t/\left(1+i_t\right)$, which, from the transaction costs technology (4) and the money velocity (5), implies the money demand:

$$m_t=K^{1/\varsigma}\left(C_t^T+C_t^N/\,e_t\right)\left(\frac{i_t}{1+i_t}\right)^{-1/\varsigma}. \quad (11)$$

The first-order condition for labor ($n_t$) implies

$$\kappa\left(1-n_t\right)^{-\zeta}=\chi\frac{w_t}{e_t}, \quad (12)$$

where $w_t \equiv W_t/\,P_t^N$ is the real wage rate in terms of nontradables. Finally, the first-order conditions also include the budget constraint (6) holding with equality and the consumption aggregator (3).

## 2.2 The Firms

### **Pricing scheme**

Extending Calvo's (1983) pricing, I assume that firms in the economy can change their pricing plans without cost with probability $(1-\alpha_L)$. However, firms can pay a lump-sum cost to increase their probability of pricing-plan revisions to $(1-\alpha_H)$, where $(1-\alpha_H) > (1-\alpha_L)$.

As in Dotsey, King and Wolman (1999), firms face a random lump-sum cost that avoids faster pricing-plan revisions. Once a firm receives the random signal to change its pricing plan it also observes the realization of the random cost $\xi \geq 0$ that the firm has to pay to increase its probability of pricing-plan revisions. The random cost $\xi$ is measured in units of nontradable output.

If the firm does not pay the random lump-sum cost $\xi$, it is subject to the lower probability of pricing-plan revisions, but it can set a new pricing-plan without additional cost. Different from Dotsey, King and Wolman (1999), firms evaluate their pricing policies infrequently. That is, with probability $(1-\alpha_j)$ for $j = H, L$, as opposed to with probability one in each period [2]. As pointed out in the introduction, infrequent evaluations of pricing policies is consistent with economies where the main restriction inhibiting flexible prices is the cost of internalizing the state of the economy in pricing decisions.

A firm paying the random cost $\xi$ at $t'$ will be subject to a probability of pricing-plan revisions $(1-\alpha_H)$ until it receives a new random signal, say at $t'+s$. Then the monopolistic firm will choose at $t'+s$ either to pay the random cost again and keep the higher probability of pricing-plan revisions, or not to pay the random cost and set its probability equal to $(1-\alpha_L)$—see Figure 1.

Extending Calvo, Celasun and Kumhof (2003) I assume that a pricing plan consists of an initial price $p^{N*}_{j,t'}(z)$, a firm specific growth rate for the firm's initial price, $\varpi_{j,t'}(z)$, and a probability of pricing-plan revisions $(1-\alpha_j)$, where $j = H, L$.

[2] In Dotsey, King and Wolman (1999) firms *evaluate* in each period their pricing policies. That is, price-setters must solve a dynamic optimization problem in each period, which requires information about the state of the economy. In their model, firms set new prices if by doing so, the value of the firm increases enough to cover a random lump-sum cost associated to the *physical cost* of changing prices.

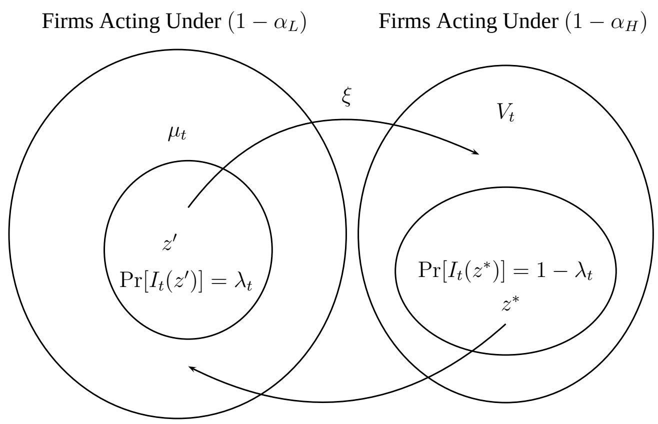


Figure 1: Pricing Mechanism

A firm can revise pricing-plans without cost with probability $(1-\alpha_L)$. The firm $z'$ setting a new pricing policy at $t$, increases its probability of pricing-plan revisions to $(1-\alpha_H)$ by paying the random lump-sum cost $\xi$ with probability $\lambda_t$. The set $V_t$ accounts for the mass of firm acting under the probability of pricing-plan revisions $(1-\alpha_H)$. The firm $z^*$ setting a new pricing policy at $t$ decides not to pay the random cost with probability $(1-\lambda_t)$ by setting pricing-policies under $(1-\alpha_L)$. The set $\mu_t$ accounts for the firms acting under $(1-\alpha_L)$.

A firm choosing a new pricing plan at $t'$ maximizes the value of the firm by choosing the triplet $\left((1-\alpha_j), p^{N*}_{j,t'}(z), \varpi_{j,t'}(z)\right)$. Given the initial price and its growth rate, the price charged by a firm choosing $(1-\alpha_j)$, evolves according to:

$$p^{N}_{j,t'+s}(z) = [\varpi_{t'}(z)]^s \, p^{N*}_{j,t'}(z), \qquad \text{for } s = 0, 1, 2 \ldots. \tag{13}$$

The time-dependent pricing rule (13) is in place until the next pricing-plan revision.

The value of a firm $z$ in period $t'$ can be described using four recursions, two of them associated to its value at $t'$, $D_{0,j,t'}$, given that $z$ is choosing $(1-\alpha_j)$, for $j = H, L$. The other two recursions are associated to the value of $z$ at $t'+s$, $D_{1,j,t'+s}$, for $s = 1, 2, 3\ldots$ and $j = H, L$, given that $z$ has not changed its pricing plan since $t'$. The four recursions account for the possibility of acting under two different probabilities of pricing-plan revisions and the two possibilities of being allowed to change pricing-plans or not. In what follows I describe the value of the firm and its optimal pricing-plan.

## The value of the firm

Consider the maximization problem for a firm receiving the random signal to revise pricing plans at $t'$. The firm decides a new pricing-plan and its probability of pricing-plan revisions. The decision is based on the value of the firm under each probability of pricing-plan adjustment.

Let $I_{t+1}(z)$ be the indicator function equal to one if $z$ chooses $(1-\alpha_H)$ at $t+1$ and zero otherwise. Let $\lambda_{t+1} \equiv \Pr[I_{t+1}(z) = 1]$ be the probability of $z$ choosing $(1-\alpha_H)$ at $t+1$. Also let $d\left(p_{j,t}^N(z), \cdot\right) \equiv \Delta_t(z)/ P_t^N$ be the real profits—in terms of nontradables—at $t$ for the firm $z$, given its price $p_{j,t}^N(z)$.

Firms choosing a pricing policy in $t'$ discount real profits received in $t'+1$ using the domestic real interest rate in terms of nontradables. The one-period ahead discount factor between $t'$ and $t'+1$ is $\omega_{t'+1} \equiv \left[\frac{(1+r)\varepsilon_{t'+1}}{\pi_{t'+1}}\right]^{-1}$.

The real value at $t'$, in terms of nontradables, of a firm subject to the probability $(1-\alpha_j)$, for $j = H, L$, which receives the random signal of pricing-plan revisions at $t'$, gross of the random cost, is given by the recursion

$$\begin{aligned} D_{0,j,t'}(S_{t'}) = \max_{\left\{p_{j,t'}^{N*}(z), \varpi_{j,t'}(z)\right\}} \Big\{ & d\left(p_{j,t'}^{N*}(z), S_{t'}\right) \\ & + \alpha_j \omega_{t'+1} D_{1,j,t'+1}\left(\varpi_{j,t'}(z) p_{j,t'}^{N*}(z),\ S_{t'+1}\right) \\ & + (1-\alpha_j)\,\omega_{t'+1}\lambda_{t'+1}\left[D_{0,H,t'+1}(S_{t'+1}) - \Xi_{t'+1}\right] \\ & + (1-\alpha_j)\,\omega_{t'+1}(1-\lambda_{t'+1})\ D_{0,L,t'+1}\big(S_{t'+1}\big)\Big\}, \end{aligned} \tag{14}$$

where $S_{t'}$ is a vector of variables describing the state of the economy at $t'$ and $\Xi_{t'+1}$, defined below, is the expected random cost conditional on choosing $(1-\alpha_H)$ at $t'+1$ with probability $\lambda_{t'+1}$ [3].

[3] Note that at the firm level firms face idiosyncratic randomness in the random lump-sum cost, however

The recursion (14) has a straightforward interpretation. For example, set $j = H$. Then, it follows from (14) that the value of the firm $z$ at $t'$ acting under $(1 - \alpha_H)$, $D_{0,H,t'}(\cdot)$, equals the profits $d\left(p^{N*}_{H,t'}(z), \cdot\right)$ plus the discounted expected value of the firm at $t' + 1$. The last three lines in (14) describe the expected value of the firm at $t' + 1$ under the three possible circumstances.

First, with probability $\alpha_H$ the firm is not allowed to change its pricing plan. Thus, it is not allowed to choose a different probability of pricing-plan adjustments. In that case, the value of the firm at $t' + 1$ is $D_{1,H,t'+1}(\cdot)$—described below.

Second, with probability $(1 - \alpha_H)$ the firm receives the random signal of pricing-plan revisions—which is strictly time dependent—thus, with probability $(1 - \alpha_H)\lambda_{t'+1}$, the firm decides to pay the random cost with conditional expected value $\Xi_{t'+1}$. In that case, the value of the firm is $[D_{0,H,t'+1} - \Xi_{t'+1}]$.

Finally with probability $(1 - \alpha_H)$ the firm is allowed to revise its pricing policy, and with probability $(1 - \lambda_{t'+1})$ the firm decides not to pay the random cost. Therefore, it will be subject to the probability of pricing-plan changes $(1 - \alpha_L)$. In that case, the value of the firm is $D_{0,L,t'+1}(\cdot)$.

Following the same principle, the value of the firm at $t' + s$, for $s = 1, 2, 3, ...$, acting under $(1 - \alpha_j)$, if it has not received the signal of pricing-plan revisions since $t'$, is

$$\begin{aligned} D_{1,j,t'+s}\left(S_{t'+s}\right) = {} & d\left(\left[\varpi_{j,t'}(z)\right]^{s} p^{N*}_{j,t'}(z), S_{t'+s}\right) \\ & + \alpha_j \omega_{t'+s+1} D_{1,j,t'+s+1}\left(\left[\varpi_{j,t'}(z)\right]^{s+1} p^{N*}_{j,t'}(z), S_{t'+s+1}\right) \\ & + \left(1 - \alpha_j\right) \omega_{t'+s+1} \lambda_{t'+s+1} \left[D_{0,H,t'+s+1}\left(S_{t'+s+1}\right) - \Xi_{t'+s+1}\right] \\ & + \left(1 - \alpha_j\right) \omega_{t'+s+1} \left(1 - \lambda_{t'+s+1}\right) D_{0,L,t'+s+1}\left(S_{t'+s+1}\right). \end{aligned} \tag{15}$$

Note that the maximization operator does not appear in (15) because the only deci-

it will become clear later that firms can have perfect foresight on the aggregate variables of the economy.

sion made is input demand, which is implicit in the definition of $d(\cdot)$. Also note that in the profit function the price of the firm is updated using the time-dependent rule (13) and such pricing policy holds until the firm receives a new random signal of pricing-plan revisions.

## Optimal pricing plan

### A) Optimal Probability of Pricing-Plan Revisions

A firm receiving the random signal of pricing-plan revisions at $t'$ chooses the high probability of pricing-plan revisions if the value of the firm—in terms of nontradables—at $t'$ under $(1-\alpha_H)$ exceeds the value of the firm at $t'$ under $(1-\alpha_L)$ by at least the random cost associated $\xi$, this is, if and only if

$$D_{0,H,t'} - D_{0,L,t'} \geq \xi\,. \tag{16}$$

Recall that the random cost $\xi$ is in units of nontradable output. Moreover, assume that $\xi$ has a cumulative density function $G(\cdot)$. Thus, before observing the realization of $\xi$, the probability of $z$ choosing $(1-\alpha_H)$ is given by $\Pr\left[D_{0,H,t'} - D_{0,L,t'} \geq \xi\right] = G\left(D_{0,H,t'} - D_{0,L,t'}\right)$.

As argued by Dotsey, King and Wolman (1999), the continuity of $G(\cdot)$ and the fact that there is a large number of firms imply that the fraction of firms choosing $(1-\alpha_H)$, conditional on receiving the random signal of pricing-plan revisions at $t'$, is

$$\lambda_{t'} = G\left(D_{0,H,t'} - D_{0,L,t'}\right).$$

Letting $g(\cdot)$ denote the density function of $\xi$, the conditional expected random cost is $\Xi_{t'} \equiv\ 1/\,G\left(D_{0,H,t'} - D_{0,L,t'}\right) \cdot \int_0^{[D_{0,H,t'}-D_{0,L,t'}]} xg(x)\mathrm{d}x$.

For parameterization purposes assume $g(\cdot) \equiv \begin{cases} \iota \exp(-\iota\xi) & \text{if } \xi \geq 0 \\ 0 & \text{if } \xi < 0 \end{cases}$, with $\iota > 0$. [4] Thus, the density function of the random lump-sum cost, implies:[5]

$$\lambda_{t'} = 1 - \exp\left(-\iota \left[D_{0,H,t'} - D_{0,L,t'}\right]\right) \tag{17}$$

and

$$\Xi_{t'} = \frac{1}{\lambda_{t'}} \left[\frac{1}{\iota} - \left(1/\iota + D_{0,H,t'} - D_{0,L,t'}\right) \cdot \exp\left(-\iota \left[D_{0,H,t'} - D_{0,L,t'}\right]\right)\right]. \tag{18}$$

**B) Optimal Pair** $\left(p^{N*}_{j,t'}(z), \varpi_{j,t'}(z)\right)$

Firm $z$ maximizes the expected present value of the firm described by (14), (15), (17) and (18) subject to the demand function (8) and the technology

$$y^N_t(z) = n_t(z), \tag{19}$$

where $y^N_t(z)$ is the total output produced by the firm, and $n_t(z)$ is the amount of labor employed. $y^N_t(z)$ has two components: output produced to satisfy consumer demand $y^N_{c,t}(z)$ and output required in pricing activities by firms incurring the random lump-sum cost, $y^N_{p,t}(z)$, that is, $y^N_t(z) \equiv y^N_{c,t}(z) + y^N_{p,t}(z)$.

Constant returns to scale imply that the total cost of production required to meet consumer demand can be written as $\psi_t y^N_{c,t}(z)$, where $\psi_t$ is the real marginal cost, in

[4] Different from Dotsey King and Wolman (1999) or Burstein (2002), I do not need to impose an upper bound for the random variable $\xi$. This is because firms have the option of not paying the random cost and still change prices, but with a lower frequency.

[5] Note that the expected random lump-sum cost is conditional on $\xi$ satisfying $[D_{0,H,t'} - D_{0,L,t'}] \geq \xi \geq 0$. Otherwise, according to (16), the firm chooses not to pay the random cost. To obtain equation (18) compute $1/\, G\left(D_{0,H,t'} - D_{0,L,t'}\right) \cdot \int_0^{[D_{0,H,t'} - D_{0,L,t'}]} x\, g(x) \mathrm{d}x$. Thus the term $1/\lambda_t$ in (18) is part of the conditional distribution.

terms of nontradables, implied by the optimal input demand.[6] This, together with the market clearing condition $c_t^N(z) = y_{c,t}^N(z)$ and the demand function (8) yields the real profit function—in terms of nontradables—gross of the random lump-sum cost:

$$d\left(p_{j,t}^N(z), S_t\right) \equiv \left[\frac{p_{j,t}^N(z)}{P_t^N} - \psi_t\right]\left(\frac{p_{j,t}^N(z)}{P_t^N}\right)^{-\theta} C_t^N, \tag{20}$$

where, as mentioned above, $p_{j,t}^N(z)$ evolves according to the time-dependent rule (13).

Consider a firm $z$ which receives the random signal to change pricing policies in $t'$. From the recursion (14), the first-order condition with respect to $p_{j,t'}^{N*}(z)$ is:

$$0 = \frac{\partial d(p_{j,t'}^N(z), S_{t'})}{\partial p_{j,t'}^{N*}(z)} + \alpha_j \omega_{t'+1} \frac{\partial D_{1,j,t'+1}(p_{j,t'+1}^N(z), S_{t'+1})}{\partial p_{j,t'}^{N*}(z)}, \tag{21}$$

where, the equation (15) implies

$$\begin{aligned} \frac{\partial D_{1,j,t'+s}(p_{j,t'+s}^N(z), S_{t'+s})}{\partial p_{j,t'}^{N*}(z)} &= \frac{\partial d(p_{j,t'+s}^N(z), S_{t'+s})}{\partial p_{j,t'}^{N*}(z)} \\ &\quad + \alpha_j \omega_{t'+s+1} \frac{\partial D_{1,j,t'+s+1}(p_{j,t'+s+1}^N(z), S_{t'+s+1})}{\partial p_{j,t'}^{N*}(z)} \end{aligned} \tag{22}$$

for $s = 1, 2, 3, \ldots$.

From the recursion (15) follows that the first-order condition for $\varpi_{t'}(z)$ is

$$\begin{aligned} \frac{\partial D_{1,j,t'+s}(p_{j,t'+s}^N(z), S_{t'+s})}{\partial \varpi_{j,t'}(z)} &= \frac{\partial d(p_{j,t'+s}^N(z), S_{t'+s})}{\partial \varpi_{j,t'}(z)} \\ &\quad + \alpha_j \omega_{t'+s+1} \frac{\partial D_{1,j,t'+s+1}(p_{j,t'+s+1}^N(z), S_{t'+s+1})}{\partial \varpi_{j,t'}(z)}. \end{aligned} \tag{23}$$

Using the profit function (20) and the time-dependent rule (13) to calculate $\partial d(\cdot)/\,\partial p_{j,t'}^{N*}(z)$ and $\partial d(\cdot)/\,\partial \varpi_{j,t'}(z)$ in (21), (22) and (23), I obtain that the optimal pair $\left(p_{j,t'}^{N*}(z), \varpi_{j,t'}(z)\right)$

[6] Marginal cost is not firm specific because labor is freely mobile.

satisfies[7]

$$\frac{p_{j,t'}^{N*}}{P_{t'}^{N}}=\frac{\theta}{\theta-1}\frac{\sum\limits_{s=0}^{\infty}\Omega_{t',t'+s}\left(\alpha_{j}\right)^{s}\left(\varpi_{j,t'}^{-\theta}\right)^{s}\left[\prod\limits_{\jmath=1}^{s}\pi_{t'+\jmath}\right]^{\theta}C_{t'+s}^{N}\psi_{t'+s}}{\sum\limits_{s=0}^{\infty}\Omega_{t',t'+s}\left(\alpha_{j}\right)^{s}\left(\varpi_{j,t'}^{(1-\theta)}\right)^{s}\left[\prod\limits_{\jmath=1}^{s}\pi_{t'+\jmath}\right]^{(\theta-1)}C_{t'+s}} \tag{24}$$

and

$$\frac{p_{j,t'}^{N*}}{P_{t'}^{N}}=\frac{\theta}{\theta-1}\frac{\sum\limits_{s=0}^{\infty}s\Omega_{t',t'+s}\left(\alpha_{j}\right)^{s}\left(\varpi_{j,t'}^{-\theta}\right)^{s}\left[\prod\limits_{\jmath=1}^{s}\pi_{t'+\jmath}\right]^{\theta}C_{t'+s}^{N}\psi_{t'+s}}{\sum\limits_{s=0}^{\infty}s\Omega_{t',t'+s}\left(\alpha_{j}\right)^{s}\left(\varpi_{j,t'}^{(1-\theta)}\right)^{s}\left[\prod\limits_{\jmath=1}^{s}\pi_{t'+\jmath}\right]^{(\theta-1)}C_{t'+s}}, \tag{25}$$

where $\Omega_{t',t'+s}\equiv\left[\prod_{\jmath=1}^{s}\omega_{t'+\jmath}\right]$ is the $s$-period ahead discount factor between $t'$ and $t'+s$.[8] Note that I use the notation $\prod_{\jmath=1}^{0}(\cdot)\equiv 1$. Moreover, I dropped the firm's index because firms choosing $(1-\alpha_j)$ at $t'$ are symmetric.

Equations (24) and (25) resemble the conditions obtained in time-dependent pricing models by Calvo, Celasun and Kumhof (2003) and by Cespedes, Kumhof and Parrado (2003). Here however, firms choose also their probability of pricing-plan revisions, $(1-\alpha_j)$, which in turn generates endogenous fluctuations in the aggregate level of nominal rigidities.

[7]To obtain the expression (24) substitute recursively (22) for $s=1,2,3\ldots$ into (21). Similarly, to obtain the expression (25) substitute recursively (23) for $s=2,3,4\ldots$ into the right-hand side of (23) for $s=1$.

[8]From the definition of $\omega_{t'}$ it follows: $\Omega_{t',t'+s}=\left[\prod_{\jmath=1}^{s}\frac{(1+r)\varepsilon_{t'+\jmath}}{\pi_{t'+\jmath}}\right]^{-1}$ with $\Omega_{t',t'}\equiv 1$.

## Evolution of average frequency of pricing-plan revisions

Let $V_t$ be the mass of firms that the last time that they revised pricing policies, before and up to $t$, they chose $(1-\alpha_H)$. I refer to this as firms acting under $(1-\alpha_H)$ at $t$—see Figure 1. Note that this implies that the mass of firms choosing $(1-\alpha_H)$ at time $t$ is $V_t - V_{t-1}$.

Similarly, let $\mu_t$ be the mass of firms acting subject to $(1-\alpha_L)$ at $t$. Given the initial conditions $\mu_{-1}$ and $V_{-1}$, the evolution of $V_t$ and $\mu_t$ can be described with the recursions:

$$V_t = V_{t-1} + \lambda_t(1-\alpha_L)\,\mu_{t-1} - (1-\lambda_t)(1-\alpha_H)V_{t-1} \tag{26}$$

$$\mu_t = 1 - V_t\,, \tag{27}$$

$$\mu_{-1} = \mu, \text{ and } V_{-1} = V\,.$$

The recursion (26) implies that the net mass of firms choosing $(1-\alpha_H)$ at $t$, $V_t - V_{t-1}$, equals the mass of firms that decided to switch from $(1-\alpha_L)$ to $(1-\alpha_H)$ at the beginning of the period, minus the mass of firms switching back from $(1-\alpha_H)$ to $(1-\alpha_L)$. Thus, the second term in equation (26) states that, at time $t$, a fraction $\lambda_t$ of the mass receiving the random signal of pricing-plan revisions (at the beginning of $t$) with low probability, $(1-\alpha_L)\mu_{t-1}$, will choose $(1-\alpha_H)$—i.e., pay the random cost. The third term states that a fraction $(1-\lambda_t)$ of firms under $(1-\alpha_H)$ decides not to pay the random cost and switches back to $(1-\alpha_L)$, i.e., $(1-\lambda_t)(1-\alpha_H)V_{t-1}$ choose $(1-\alpha_L)$.

Equation (27) holds because the mass of firms is constant and equal to one, so that $V_t + \mu_t = 1$ for all $t = 0,\, 1,\, 2\ldots$. The initial conditions are determined by the steady state of the economy.

Assuming that each period represents one quarter, it follows that, in average, firms in the economy change pricing policies

$$F_t \equiv (1-\alpha_L)\mu_t + (1-\alpha_H)(1-\mu_t) \tag{28}$$

times per quarter. Note that, although the expected frequency of pricing-plan revisions can take only two values at firm level, the average frequency of pricing-plan revisions at the aggregate level, $F_t$, is a double-bounded continuous function, with upper and lower bounds $(1-\alpha_H)$ and $(1-\alpha_L)$, respectively.

## **The price level**

To aggregate prices, it is convenient to rewrite the price index for nontradables $P_t^N \equiv \left[\int_0^1 [p_t^N(z)]^{1-\theta} \mathrm{d}z\right]^{\frac{1}{1-\theta}}$ as:

$$P_t^N \equiv \left[\mu \left(P_{L,t}^N\right)^{1-\theta} + (1-\mu)\left(P_{H,t}^N\right)^{1-\theta}\right]^{\frac{1}{1-\theta}} \tag{29a}$$

with $P_{L,t}^N \equiv \left[\frac{1}{\mu}\int_0^{\mu_t} [p_t^N(\hat{z})]^{1-\theta} \mathrm{d}\hat{z}\right]^{\frac{1}{1-\theta}}$ and $P_{H,t}^N \equiv \left[\frac{1}{1-\mu}\int_{\mu_t}^1 [p_t^N(\hat{z})]^{1-\theta} \mathrm{d}\hat{z}\right]^{\frac{1}{1-\theta}}$. The index $\hat{z} \in [0,1]$ is chosen so that the integral in the subindex $P_{j,t}^N$ aggregates prices of firms acting subject to $(1-\alpha_j)$ in time $t$.

As in the standard Calvo (1983)-Yun (1996) framework, given the assumption of a constant probability of changing pricing policies, the price sub-index $P_{j,t}^N$ can be expressed as a weighted average of prices optimally chosen in the past—weighted by $\alpha_j$. However, different from time-dependent pricing models, the mass of firms setting a new pricing policy under $(1-\alpha_j)$ changes with the state of the economy. Accordingly, we can express the price sub-indexes as:

$$\left(P_{L,t}^{N}\right)^{1-\theta} = \frac{1}{\mu}\sum_{s=0}^{\infty}\left(\alpha_L\right)^s\left[(1-\alpha_L)\mu_{t-s-1}\right.$$
$$\left.-\left(V_{t-s}-V_{t-s-1}\right)\right]\left[p_{L,t-s}^{N*}\left(\varpi_{L,t-s}\right)^s\right]^{1-\theta} \quad (29b)$$

and

$$\left(P_{H,t}^{N}\right)^{1-\theta} = \frac{1}{1-\mu}\sum_{s=0}^{\infty}\left(\alpha_H\right)^s\left[(1-\alpha_H)(1-\mu_{t-s-1})\right.$$
$$\left.+\left(V_{t-s}-V_{t-s-1}\right)\right]\left[p_{H,t-s}^{N*}\left(\varpi_{H,t-s}\right)^s\right]^{1-\theta}. \quad (29c)$$

In the sub-index $P_{L,t}^{N}$ above, the mass of firms setting the new pair $\left(p_{L,t-s}^{N*}, \varpi_{L,t-s}\right)$ at $t-s$ is expressed as the mass of firms that had the opportunity to revise pricing policies at the beginning of the period $t-s$, $(1-\alpha_L)\mu_{t-s-1}$, minus the net mass of those that decided to choose $(1-\alpha_H)$, $(V_{t-s}-V_{t-s-1})$. Similarly, in the sub-index $P_{H,t}^{N}$, the mass of firms setting a new pair $\left(p_{H,t-s}^{N*}, \varpi_{H,t-s}\right)$ under $(1-\alpha_H)$ is expressed as the mass of firms under the high probability that received the random signal of pricing-plan changes at the beginning of the period $t-s$, $(1-\alpha_H)(1-\mu_{t-s-1})$, plus the net mass of firms choosing $(1-\alpha_H)$ at $t-s$, this is, $(V_{t-s}-V_{t-s-1})$.

The price index described by (29a), (29b) and (29c) contains as especial case the price index based in time-dependent pricing policies discussed in Calvo, Celasun and Kumhof (2003) or Cespedes, Kumhof and Parrado (2003).

To see that, consider a situation in which the cost to revise pricing policies more frequently is sufficiently high such that firms keep the low probability of pricing-policy revisions under any state of the economy. Then from the condition (16) it follows that $\lambda_t = 0\ \forall t$ and from the equations (26)-(27) follows that $\mu_t = \mu = 1\ \forall t$ and $V_t = V = 0$

$\forall t$.[9] Moreover, from the price indexes (29a)-(29c) we obtain:

$$\left(P_t^N\right)^{1-\theta} = (1-\alpha_L)\sum_{s=0}^{\infty}(\alpha_L)^s\left[p_{L,t-s}^{N*}\left(\varpi_{L,t-s}\right)^s\right]^{1-\theta}.$$

This is the price index presented in Calvo et al. (2003) for an open economy and in Cespedes et al. (2003) for a closed economy.

In the general case however, the cost of additional pricing-plan revisions is not restrictive, thus the evolution of the mass of firms choosing to revise pricing policies more frequently shapes the dynamics of the price index.

## 2.3 Government

The fiscal authority holds a stock of internationally traded bonds, $b_{g,t}$, denominated in units of tradable goods. The monetary authority issues money at the gross rate $\varrho_t \equiv M_t/M_{t-1}$ and makes lump-sum transfers $a_t$. The consolidated budget constraint of the government, in terms of tradables, is

$$b_{g,t-1}(1+r) + \frac{M_t - M_{t-1}}{\mathscr{E}_t} = b_{g,t} + a_t, \tag{30}$$

for which, the no Ponzi game condition $\lim_{t\to\infty}\frac{b_{g,t}-m_t}{(1+r)^t} = 0$ holds. Note that the money growth rate $\varrho_t$ implies

$$m_t = \frac{\varrho_t}{\varepsilon_t} m_{t-1}. \tag{31}$$

To close the model I specify the path for the depreciation rate $\{\varepsilon_t\}_{t=0}^{\infty}$ or alternatively the path for the money growth rate $\{\varrho_t\}_{t=0}^{\infty}$ in the context of policy experiments in the next section. Appendix A states a formal definition of equilibrium for the economy and

[9] In numerical simulations, a high enough mean of the random cost (e.g. $E[\xi] = 1/\iota = 1e^3$) produces $\lambda_t \cong 0 \forall t$, $\mu_t \cong 1$ and $V_t \cong 0\ \forall t$ as shown in the next section.

its characterization as a system of equations.

# 3 Stabilization Programs: Dynamics

## 3.1 Solution Algorithm and Calibration

I solve the model using an iterative backward recursion algorithm. That method is used for example by Golosov and Lucas (2003) or Burstein (2002) for state-dependent pricing models for closed economies and by Mendoza and Uribe (1997) for an open economy with flexible prices.

Following Golosov and Lucas (2003),[10] the algorithm assumes that there is a period $t = \mathrm{T}$ when the economy reaches a new steady state. i) I make an initial guess for the path of the aggregate variables $\{C_t^N, \pi_t, \psi_t\}_{t=0}^{\infty}$, given that guess ii) I solve the for the firm level prices $\{\nu_{j,t}^*, \varpi_{j,t}\}_{t=0}^{\infty}$ from the system (24)-(25) with $j = H, L$ and iii) I use that sequence to aggregate prices together with the household's first-order conditions and budget constraints to construct the implied path of $\{C_t^N, \pi_t, \psi_t\}_{t=0}^{\infty}$. If each element of the guess in i) and the path found in iii) have a difference smaller than $1e^{-6}$ I stop, otherwise I iterate over i), ii) and iii) to find convergence.

### Calibration

I calibrate the economy using parameter values often used in the literature of disinflation programs for small open economies. The discount factor ($\beta = 0.984$) implies a real rate of return of $6.5$ percent annually. The parameter $\Gamma = 1$ corresponds to a logarithmic utility function in (the quasidifference of) consumption. $\gamma = 0.5$ is the elasticity of the

[10]Golosov and Lucas (2003) study credible and noncredible permanent disinflation programs under perfect foresight—among other experiments—for a state-dependent pricing model in a closed economy.

| Parameter Value | Description |
|---|---|
| | **Preferences** |
| $\beta = .984$ | subjective discount factor |
| $\gamma = .5$ | elasticity of consumption aggregator w.r.t. tradables |
| $\varphi = .5$ | habit parameter |
| $\theta = 6$ | own price-elasticity of nontradables |
| $\zeta = 3$ | inverse wage-elasticity of labor supply |
| $\kappa = 0.124$ | preference parameter |
| $\Gamma = 1$ | preference parameter |
| | **Pricing mechanism** |
| $(1-\alpha_L) = .2$ | lower bound for average frequency of pricing-plan revisions ($F_t$) |
| $(1-\alpha_H) = .5$ | upper bound for average frequency of pricing-plan revisions ($F_t$) |
| $\iota = 1/0.005$ | inverse of expected random cost in units of nontradable output |
| | **Transaction Costs and Endowments** |
| $K = 3.8$ | scale parameter in transaction costs technology |
| $\varsigma = 1/0.2$ | inverse elasticity of money demand w.r.t. $i_t/(1+i_t)$ |
| $Y^T = 1/3$ | endowment of tradables |
| $b_{-1} = b_{g,-1} = 0$ | initial stocks of bonds (households and government respectively) |
| | **Monetary Policy** |
| $\varepsilon^h (= \varrho^h) = 1.27$ | Quarterly gross devaluation (money growth) rate before the program |
| $\varepsilon^l (= \varrho^l) = 1.024$ | Quarterly gross devaluation (money growth) rate during the program |
| $\tau = 12$ | Time duration of the program in quarters (temporary program) |

Table 1: Baseline Calibration

consumption aggregator with respect to tradables. The own-price elasticity of demand for nontradables ($\theta = 6$) implies a steady-state markup of 20 percent above marginal cost.

The value of $\kappa$ in the utility function is chosen such that in the pre-announcement steady-state households allocate one third of the endowed time to labor ($\kappa = 0.124$ implies $n = 1/3$). The wage elasticity of labor supply is $1/\zeta$, which I set to $1/3$. As in Uribe (2002) preferences show non-separability over time with $\varphi = 0.5$. However I also analyze the case of $\varphi = 0$ in the subsection 3.4.

The elasticity of money demand with respect to $i_t/(1+i_t)$ is $1/\varsigma$ in equation (11). A value of $\varsigma = 1/0.2$ is consistent with empirical estimates provided by Reinhart and Végh (1995). Moreover, substituting the money demand (11) into the money velocity (5) yields the money velocity as a function of the nominal interest rate: $u_t = K^{-\frac{1}{\varsigma}} \left(\frac{i_t}{1+i_t}\right)^{\frac{1}{\varsigma}}$.

Following Mendoza and Uribe (1997), the value of $K$ in the transaction costs technology is such that in the pre-stabilization steady-state, the money velocity is $0.32$ ($K = 3.8$). The endowment of tradables is $Y^T = 1/3$ and the initial stocks of bonds are set to zero ($b_{-1} = b_{g,-1} = 0$).

To make the results comparable with the existing literature of disinflation programs in small open economies, the parameters of the pricing mechanism are chosen to stay close to the standard time-dependent model. At the firm level $(1 - \alpha_L) = 0.2$ implies that firms subject to the low probability of pricing-plan revisions set new pricing-policies once every five quarters on average; $(1-\alpha_H) = 0.5$ implies that, under the high probability of pricing-plan adjustments, firms revise pricing-policies twice per year on average. At the aggregate level, these values imply an upper and lower bound on fluctuations of the average frequency of pricing-plan revisions of 2 and 0.8 revisions per year, respectively.

Consistent with Dotsey, King and Wolman's (1999) calibration, the parameter $\iota$ in the distribution of the random cost $G(\cdot)$ implies that the unconditional expected cost is $0.005$ units of nontradable output ($E(\xi) = 1/\iota = 0.005$).

In each experiment I also simulate the economy for the case in which the degree of nominal rigidities is constant. To do that, I set the unconditional mean of of the random lump-sum cost to one thousand units of nontradable output ($E(\xi) = 1/\iota = 1e^3$). As discussed above (p. 19) when the random lump-sum cost is restrictive, the price index of the economy resemble the time-dependent price index proposed in Calvo, Celasun and Kumhof (2001) for an open economy.

Finally, note that the high probability of pricing-plan revisions, the relevant probability for the special case of constant nominal rigidities, is in line with values used in the literature. For example, Schmitt-Grohé and Uribe's (2001) calibration for the Mexican economy implies that firms on average change prices every nine months; Calvo et al. (2003) calibrate their model such that firms change pricing plans every twelve months on average. The benchmark calibration in the special case of constant nominal rigidities implies that firms change pricing policies every fifteen months on average. Nevertheless, in the subsection 3.5, I perform sensitivity analysis in this regard by assuming that firms subject to the low probability change pricing-policies every 8.4 months on average.

## 3.2 Permanent and Credible Stabilization

A permanent and credible exchange rate-based (ERB) disinflation program is defined as a reduction of the exchange rate depreciation from $\varepsilon^h$ to $\varepsilon^l$, which occurs in $t = 0$. That is:

$$\varepsilon_t = \begin{cases} \varepsilon^h \text{ for } t < 0 \\ \varepsilon^l \text{ for } t \geq 0 \, , \end{cases} \tag{32}$$

where $\varepsilon^h > \varepsilon^l$.

Similarly, in a permanent and credible money-based (MB) disinflation program the monetary authority reduces the money growth rate from $\varrho^h$ to $\varrho^l$ in $t = 0$. That is:

$$\varrho_t = \begin{cases} \varrho^h \text{ for } t < 0 \\ \varrho^l \text{ for } t \geq 0 \, , \end{cases} \tag{33}$$

where $\varrho^h > \varrho^l$.

Consistent with Mexico's 1987 ERB disinflation experience, I calibrate the ERB program (32) and the MB program (33) with an initial inflation rate of $160$ percent per year ($\varepsilon^h = \varrho^h = 1.27$) and a low inflation rate of $10$ percent per year ($\varepsilon^l = \varrho^l = 1.024$).

Figure 2 displays the dynamics of permanent and credible ERB and MB programs.

For the ERB program (Figure 2(a)), the model predicts a sustained boom in consumption of tradables and nontradables, whereas for the MB program (Figure 2(b)), the model predicts an initial short-lived recession in the nontradable sector.

The lower right plots in Figures 2(a) and 2(b) show that when firms confront a once-and-for-all disinflation, in a perfect foresight equilibrium, they find optimal to adjust their pricing policies mostly through their time-dependent pricing rule (13), instead of updating pricing policies more often. That is, the frequency of pricing-plan revisions displays a small response to the monetary shock.

At the firm level, in the permanent ERB program, price-setters are willing to spend about 2.2 percent of their profits in increasing the frequency of pricing-plan revisions from one revision every five quarters to one revision per year. Such incentive however, only lasts for two quarters. A similar situation occurs in a permanent MB program. Hence, as shown in Figure 2, in permanent and credible ERB and MB programs the dynamics of the model with state-dependent nominal rigidities (solid line) is very close its special case of purely time-dependent pricing (dashed line). As shown below, this result is specific to permanent and credible disinflations.

Permanent and credible stabilization programs are illustrative, but they are highly unrealistic. As pointed out by Calvo and Végh (1999), a common characteristic of stabilization programs is imperfect credibility. I explore the effects of lack of credibility in the next two experiments.

## 3.3 Temporary Stabilization

Calvo (1986) proposes to address lack of credibility in stabilization programs by formally modeling the stabilization episode as temporary. Following Calvo (1986), in a temporary exchange rate-based disinflation the monetary authority reduces the depreciation rate from $\varepsilon^h$ to $\varepsilon^l$ for $\tau$ quarters. That is,

$$\varepsilon_t = \begin{cases} \varepsilon^h \text{ for } t < 0 \\ \varepsilon^l \text{ for } t \in [0, \tau) \\ \varepsilon^h \text{ for } t \geq \tau \, . \end{cases} \tag{34}$$

In a temporary money-based disinflation program the monetary authority reduces the money growth rate from $\varrho^h$ to $\varrho^l$ for $\tau$ quarters. That is,

$$\varrho_t = \begin{cases} \varrho^h \text{ for } t < 0 \\ \varrho^l \text{ for } t \in [0, \tau) \\ \varrho^h \text{ for } t \geq \tau \, . \end{cases} \tag{35}$$

The temporary programs (34) and (35) are calibrated with $\varepsilon^h = \varphi^h = 1.27$, $\varepsilon^l = \varphi^h = 1.024$ and $\tau = 12$. These values imply a pre-announcement steady-state inflation rate of $160$ percent per year and a temporary target for the inflation rate of $10$ percent per year. The program is in place for twelve quarters and the low-inflation target is abandoned thereafter.

Figure 3(a) captures the main result of the paper. In ERB temporary disinflations, the model with state-dependent nominal rigidities (solid line) predicts a sustained boom in nontradables—i.e., the sector with nominal rigidities,—followed by a later recession. The peak of the boom is reached in the eighth quarter after the implementation of the program. In contrast, in the special case of constant nominal rigidities (dashed line) the recession in nontradables sets forth just after the announcement of the program [11].

The intuition for this result is clear. The lower right panel of Figure 3(a) shows that

[11] In time-dependent models, the prediction that the recession phase starts immediately after the beginning of the program is also found in Calvo, Celasun and Kumhof (2003) or in Uribe (1999). That is however, at odds with empirical evidence.

the average frequency of pricing-plan revisions grows from one revision per year on impact, to two revision per year by the end of the program. That is, as the program goes on, the economy faces a gradually lower degree of nominal rigidities. That in turn, allows for a sustained expansion in nontradables.

At the microeconomic level, Figure 3(a) shows that when the ERB program is perceived as temporary, firms have a strong incentive to adjust their pricing policies more often in order to accommodate the new state of the economy. Firms are willing to spend between five and six percent of their profits in additional pricing-plan revisions. Such incentive lasts for almost the entire duration of the program. This quantitative result is in line with firm-level evidence on the cost of pricing activities presented in Zbaraki et al. (2003) [12].

Figure 3(a) also shows that the initial equilibrium path of other key macroeconomic variables is in accordance with observed ERB disinflation episodes. Namely, a gradual fall in inflation, an initial appreciation of the real exchange rate and a boom-recession cycle in the tradable sector [13].

Figure 3(b) shows the dynamics of the temporary MB program. Both models predict an initial short-lived recession in the nontradable sector followed by a recovery. The initial adverse effect in nontradables is of about the same magnitude with constant or with state-dependent nominal rigidities. On the other hand, the equilibrium paths differ. State-dependent nominal rigidities allow for a faster recovery that brings the nontradable

[12]Zbaraki et al. (2003) document price adjustment practices for a U.S. industrial manufacturer. They find that the firm's cost of pricing activities represents 4.05 percent of the gross profit margin, that is 1.22 percent of their revenues.

[13]The model fails to predict however, a sustained real exchange rate appreciation. That feature combined with a boom-recession cycle in tradables and nontradables is known in the literature as *the price-consumption puzzle*. Uribe (2002) proposes the introduction of habit formation as a solution for the price-consumption puzzle. Moreover, Mendoza and Uribe (1997) rationalize those facts in programs of uncertain duration. In numerical simulations, the aforementioned papers assume flexible prices and impose asymmetries in the production of tradables and nontradables. In particular, they assume investment in the tradable sector. I do not attempt to pursue such task here.

sector to higher levels than its pre-disinflation level. Note however that, as shown in the next section, when the program is of uncertain duration, the recovery phase in the nontradable sector is weaker.

### 3.4 Program with Uncertain Duration

Following Mendoza and Uribe (1999), in a ERB (MB) program with uncertain duration, the monetary authority announces at time $t = 0$ a reduction in the depreciation rate (money growth rate) from $\varepsilon^h (= \varrho^h) = 1.27$ to $\varepsilon^l (= \varrho^l) = 1.024$. Agents assign a time-dependent probability to the abandonment of the program in the next period. That is, the public expects in date $t$ the program to be abandoned at $t + 1$ with probability $h_t \equiv \Pr(\varepsilon_{t+1} = \varepsilon^h | \varepsilon_t = \varepsilon^l)$—similarly for MB programs I define $h_t \equiv \Pr(\varrho_{t+1} = \varrho^h | \varrho_t = \varrho^l)$. I also assume that the program ends with probability one in the period $t = \tau$, that is $h_{\tau-1} = 1$. Moreover, $\varepsilon^h$ is an absorbent state in the sense that once $\varepsilon^h$ is realized, the monetary authority keeps the high depreciation rate with probability one.

Based on empirical evidence on devaluation probabilities provided by Blanco and Garber (1986), the hazard function assumed is J-shaped. As shown in the upper right panel of Figures 4(a) and 4(b), the hazard function implies that when the disinflation is announced, the public expect that the program will collapse in $t = 1$ with probability 0.4 ($h_0 = 0.4$), the probability of collapse decreases to zero in the fourth quarter ($h_4 = 0$) and then rises gradually to one in the eleventh quarter ($h_{11} = 1$), that is, the program lasts at most 12 quarters.

Figure 4 shows the dynamics of key macroeconomic variables for the ERB and MB programs with uncertain duration. The solid line (—) shows the equilibrium path for the model with state-dependent nominal rigidities under the scenario that the program lasts for exactly 12 quarters. The mark (+) shows the alternative value at $t$ of the corresponding variable if the program is abandoned at $t$ (the remaining path under such state is not shown). Finally, the dashed line ($--$) shows the equilibrium path for the special case of constant nominal rigidities when the program lasts for 12 quarters. To isolate the effects of habit formation, this experiment assumes time separability in consumption ($\varphi = 0$), and all other parameters values as those in Table 1.

Figure 4(a) shows that the qualitative properties of the model discussed in the last subsection for a temporary ERB program also hold when agents perceive the program as of uncertain duration. In particular, in the model with endogenous nominal rigidities (solid line) the peak of the boom in nontradables occurs six quarters after the program is announced. In its peak level, consumption of nontradables is eight percent above its pre-disinflation level. The later recession drops the level of nontradables to ten percent below its pre-disinflation level by the end of the program.

In contrast, constant nominal rigidities (dashed line) induces a jump on impact in the nontradable sector of about two percent, followed by a deep contraction that sets the level of nontradables 20 percent below its pre-disinflation level. The equilibrium path of inflation, the real exchange rate and consumption of tradables resemble the one induce by the temporary ERB program discused in the last subsection.

On the other hand, Figure 4(b) displays the equilibrium path induced by a MB program of uncertain duration. When we account for uncertainty, both models predict an initial contraction in nontradables of about 12 percent, followed by a recovery. Different from the previous experiment, in the case of state-dependent nominal rigidities, the consumption of nontradables remains below its pre-disinflation level during its equilibrium path.

## 3.5 Sensitivity Analysis

I perform sensitivity analysis in four key parameter values. First, there is little empirical evidence on the degree of nominal rigidities in small open economies, thus although the baseline parameter values are in the range of those commonly used in the literature, I also calibrate a lower degree of nominal rigidities by setting $(1 - \alpha_H) = 0.7$ and $(1 - \alpha_L) = 0.3$.

Second, the time duration of temporary disinflation programs varies widely. For example, Mexico's 1987 ERB program lasted about 28 quarters, whereas Brazil's 1986 ERB program lasted about 4 quarters. The benchmark calibration is for 12 quarters, thus I also simulate a program that lasts 24 quarters.

Third, for developing countries the range of estimates for the elasticity of money demand with respect to its opportunity cost ($i/(1 + i)$) is large. From -0.5 for Mexico to -0.1 for Argentina (e.g. Arrau et al. [1995]). The benchmark calibration assumes a money demand elasticity of -0.2, the alternative value chosen is -0.5. Finally, the related literature often assume logarithmic utility in leisure. I also do so as a robustness check.

Using the alternative parameterization discused above, Figures 5 and 6 show the equilibrium path of inflation, real exchange rate, consumption of tradables and consumption of nontradables for temporary ERB and MB disinflation programs, respectively.

The simulations with the alternative calibrations confirm that for temporary ERB disinflations, the qualitative discrepancies in the dynamics of nontradables (the sector with nominal rigidities) across economies with and without endogenous degree of nominal rigidities hold. Moreover, for temporary MB programs both models predict and initial short-lived contraction in nontradables of about the same order of magnitude.

# 4 Concluding Remarks

Nominal rigidities have proven central in the understanding of business cycle fluctuations. However, most of the existing literature characterizes the degree of nominal rigidities as an exogenous feature embedded in pricing practices at the microeconomic level. That not only isolates the effects of macroeconomic policies on the speed of adjustment of firms' pricing policies, but in turn isolates the effects of endogenous fluctuations of the aggregate degree of nominal rigidities on macroeconomic variables.

This paper builds on the firm-level pricing theory proposed by Calvo (1983) by adding elements of state-dependent pricing. Whereby price-setters can set optimal pricing policies more often when confronted with macroeconomic shocks. That new feature shows to be important in explaining business cycle fluctuations in consumption associated to exchange rate-based disinflation programs of the type of those implemented in several Latin American economies. At the same time, the model shows to be capable of generating dynamics qualitatively consistent with money-based disinflation episodes.

The model can be extended in several aspects to improve its quantitative properties. An extension of interest is the incorporation of more realistic production structures. Finally, I must point out that the paper relies on transmission mechanisms widely discussed in the literature of disinflation programs. Namely, supply-side effects, nominal rigidities and intertemporal effects of temporary disinflations.

# A Appendix A: Equilibrium

In ERB programs, given a sequence of real money balances, a *government policy* is defined by a sequence of transfers and exchange rate depreciation $\{a_t, \varepsilon_t\}_{t=0}^{\infty}$. In MB programs, given a sequence of exchange rate depreciation, a *government policy* is defined by a sequence of transfers and money growth rate $\{a_t, \varrho_t\}_{t=0}^{\infty}$. An *allocation* is a sequence of aggregate consumption, consumption of tradables, consumption of nontradables, labor, real money balances, money velocity and production of nontradables $\{C_t, C_t^T, C_t^N, n_t, m_t, u_t, c_t^N(z), y_t^N(z), n_t(z)\ \forall z\}_{t=0}^{\infty}$. A *price system* is a sequence of interest rates, wages and prices $\{i_t, W_t, P_t^N, p_t^N(z)\ \forall z\}_{t=0}^{\infty}$.

An *equilibrium* given $b_{-1}$ and $b_{g,-1}$ is an allocation, a price system and a government policy such that: i) given a price system and a government policy, the representative household chooses $\{C_t, C_t^T, C_t^N, n_t, m_t, u_t, c_t^N(z), \forall z\}_{t=0}^{\infty}$ to maximize the utility index described by (2) and (7) subject to (3), (4), (5) and (6). ii) Given a government policy, firms $z \in [0,1]$ choose $p_t^N(z)$ to maximize the value of the firm described by equations (14), (15), (17) and (18) subject to (8) and (19), where the relation between $p_t^N(z)$ and $P_t^N$ is given by (13), (29a), (29b) and (29c). iii) The nontradable goods market clears $c_t^N(z) = y_{c,t}^N(z)\,\forall z$, the labor market clears $n_t = \int_0^1 n_t(z)\mathrm{d}z$ at a wage rate $W_t$.

## Characterization of a perfect foresight equilibrium

Substituting the money demand (11) into the money velocity (5) yields

$$u_t = K^{-\frac{1}{\varsigma}} \left( \frac{i_t}{1+i_t} \right)^{1/\varsigma}, \tag{36}$$

this together with the transaction costs technology (4) in the first-order condition (9) imply

$$\gamma\left[\left(C_t-\varphi C_{t-1}\right)^{-\Gamma}-\beta\varphi\left(C_{t+1}-\varphi C_t\right)^{-\Gamma}\right]\left(\frac{C_t^N}{C_t^T}\right)^{1-\gamma}=\chi\left[1+K^*\left(\frac{i_t}{1+i_t}\right)^{\frac{\varsigma-1}{\varsigma}}\right], \tag{37}$$

where $K^*\equiv K^{1/\varsigma}\,\varsigma/\left(\varsigma-1\right)$.

Substituting the government budget constraint (30) into the household budget constraint (6), using the the first-order condition (10) to eliminate $C_t^N/e_t$ from the resulting expression I obtain

$$\left(b_{-1}+b_{g,-1}\right)\left(1+r\right)=\sum_{t=0}^{\infty}\left(\frac{1}{1+r}\right)^t\left\{C_t^T\left[1+\frac{1}{\gamma}s(u_t)\right]-Y^T\right\}. \tag{38}$$

From the price indexes (29a)-(29c)[14]:

$$\begin{aligned}\pi_t \;=\; & \sum_{s=0}^{\infty}\left(\alpha_L\right)^s\left[(1-\alpha_L)\mu_{t-s-1}-\left(V_{t-s}-V_{t-s-1}\right)\right]\left[\nu^*_{L,t-s}\frac{\left(\varpi_{L,t-s}\right)^s}{\prod_{\jmath=1}^{s-1}\pi_{t-\jmath}}\right]^{1-\theta}+ \qquad (39)\\ & \sum_{s=0}^{\infty}\left(\alpha_H\right)^s\left[(1-\alpha_H)(1-\mu_{t-s-1})+\left(V_{t-s}-V_{t-s-1}\right)\right]\left[\nu^*_{H,t-s}\frac{\left(\varpi_{H,t-s}\right)^s}{\prod_{\jmath=1}^{s-1}\pi_{t-\jmath}}\right]^{1-\theta}.\end{aligned}$$

Consider the real exchange rate definition $e_t=E_t/P_t^N$ thus $\frac{e_t}{e_{t-1}}=\frac{E_t}{E_{t-1}}\frac{P_{t-1}^N}{P_t^N}=\frac{\varepsilon_t}{\pi_t}$. Rewrite the last expression as

$$e_t=\frac{\varepsilon_t}{\pi_t}e_{t-1}. \tag{40}$$

As in Yun (1996), define the alternative price index $\overline{P}_t\equiv\left[\int_0^1\left(p_t^N(z)\right)^{-\theta}\mathrm{d}z\right]^{-1/\theta}$ and the aggregate production by $Y_{c,t}^N\equiv\int_0^1 y_{c,t}^N(z)\mathrm{d}z$. Moreover define the ratio of price indexes $\overline{R}_t\equiv\overline{P}_t/P_t$, then from the market clearing condition for nontradables

[14] Note that $\pi_t$ appears on both sides of 39, but from that equation we can “solve” for $\pi_t$.

$\int_0^1 y_{c,t}^N(z) = \int_0^1 n_t(z)$:

$$n_t = \left(\overline{R}_t\right)^{-\theta} C_t^N. \tag{41}$$

The ratio of price indexes $\overline{R}_t$ can be written as

$$\begin{aligned}\left(\overline{R}_s\right)^{-\theta} \quad = \quad & \sum_{i=0}^{\infty} (\alpha_L)^i \left[(1-\alpha_L)\mu_{s-1-i} - (V_{s-i} - V_{s-1-i})\right] \left[\nu_{L,s-i}^* \frac{\varpi_{L,s-i}^i}{\prod_{\jmath=1}^i \pi_{s-\jmath}}\right]^{-\theta} \\ & \sum_{i=0}^{\infty} (\alpha_H)^i \left[(1-\alpha_H)(1-\mu_{s-1-i}) + (V_{s-i} - V_{s-1-i})\right] \left[\nu_{H,s-i}^* \frac{\varpi_{H,s-i}^i}{\prod_{\jmath=1}^i \pi_{s-\jmath}}\right]^{-\theta}.\end{aligned} \tag{42}$$

Finally, from the production technology we obtain the marginal cost:

$$\psi_t = w_t. \tag{43}$$

For an ERB program, given a sequence for the deprecation rate $\varepsilon_t$, equations (1), (3), (4), (10), (11), (12), (17), (18), (20), (26), (27), (28), (31), (36)-(43) and (14), (15), (24) and (25) for $j = H, L$ is a system of $29$ equations in $28$ variables and one scalar (the Lagrange multiplier): $C_t$, $C_t^N$, $C_t^T$, $n_t$, $i_t$, $s_t$, $m_t$, $u_t$, $\pi_t$, $e_t$, $w_t$,$\varrho_t$, $\overline{R}_t$, $\lambda_t$, $d_t$, $\Xi_t$, $V_t$, $\mu_t$, $F_t$, $\psi_t$, $D_{0,H,t}$, $D_{1,H,t}$, $D_{0,L,t}$, $D_{1,L,t}$, $\nu_{H,t}^*$, $\nu_{L,t}^*$, $\varpi_{H,t}$, $\varpi_{L,t}$ and $\chi$. Its solution characterize an equilibrium [15].

For a MB program, given a sequence for the money growth rate $\varrho_t$, equations (1), (3), (4), (10), (11), (12), (17), (18), (20), (26), (27), (28), (31), (36)-(43) and (14), (15), (24) and (25) for $j = H, L$ is a system of $29$ equations in $28$ variables and one scalar (the Lagrange multiplier): $C_t$, $C_t^N$, $C_t^T$, $n_t$, $i_t$, $s_t$, $m_t$, $u_t$, $\pi_t$, $e_t$, $w_t$,$\varepsilon_t$, $\overline{R}_t$, $\lambda_t$, $d_t$, $\Xi_t$, $V_t$, $\mu_t$, $F_t$, $\psi_t$, $D_{0,H,t}$, $D_{1,H,t}$, $D_{0,L,t}$, $D_{1,L,t}$, $\nu_{H,t}^*$, $\nu_{L,t}^*$, $\varpi_{H,t}$, $\varpi_{L,t}$ and $\chi$. Its solution characterize an equilibrium.

[15] Note that the initial and final conditions are given by the pre-disinflation and post-disinflation steady-states, respectively.

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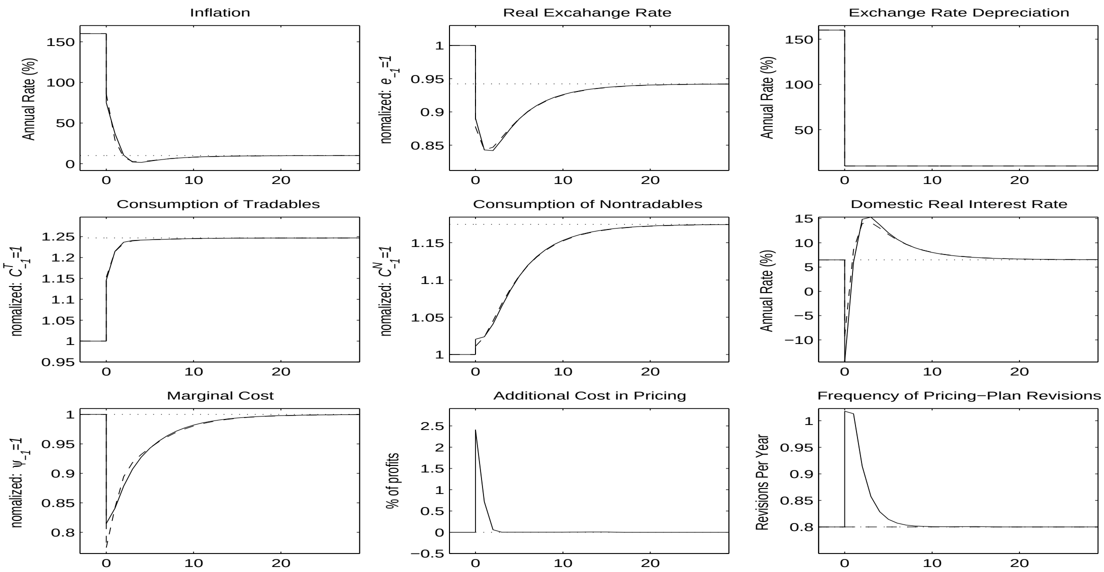
(a) Permanent Exchange Rate-Based Disinflation Program




(b) Permanent Money-Based Disinflation Program

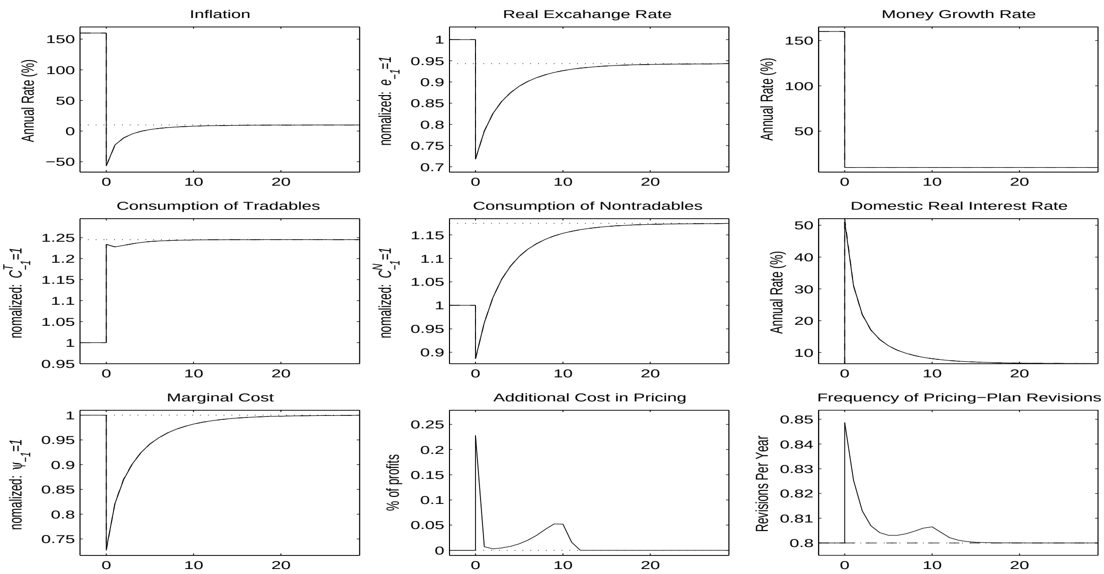
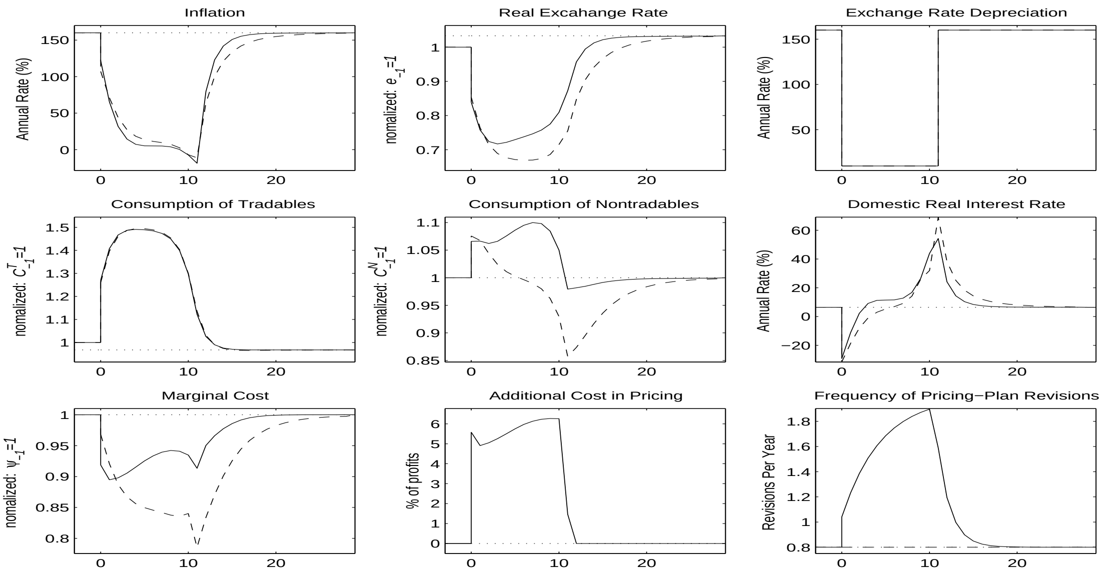



Figure 2: Permanent and Credible Disinflation Programs

The permanent ERB (MB) disinflation program consists in a reduction of the depreciation rate (money growth rate) from 160 to 10 percent per year in $t = 0$. The solid line (—) shows the model with state-dependent nominal rigidities. The dashed line ($--$) shows the special case with constant nominal rigidities. The parameter values are those in Table 1.

(a) Temporary Exchange Rate-Based Disinflation Program




(b) Temporary Money-Based Disinflation Program

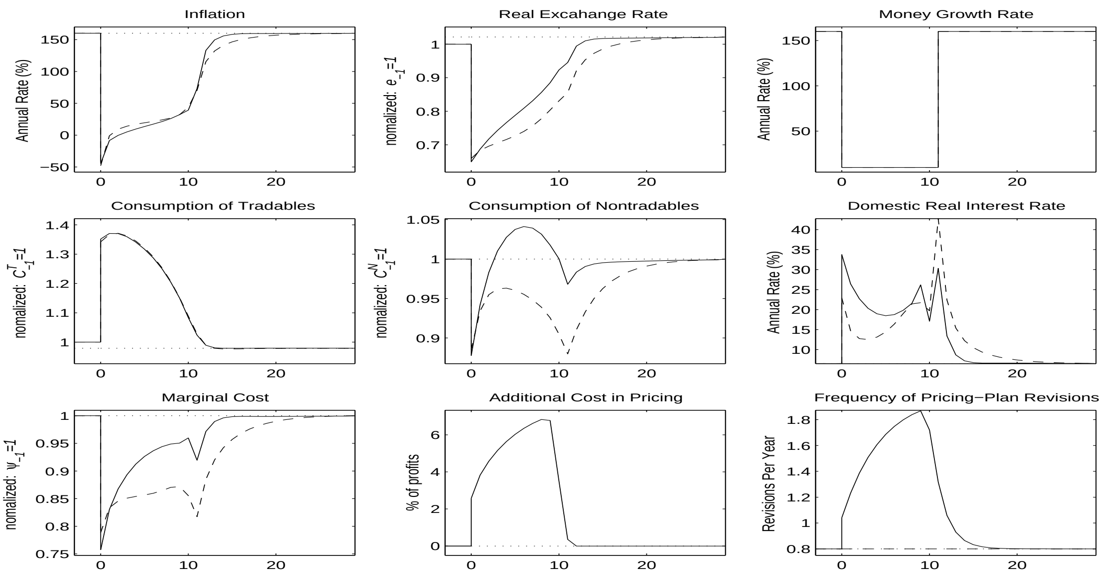
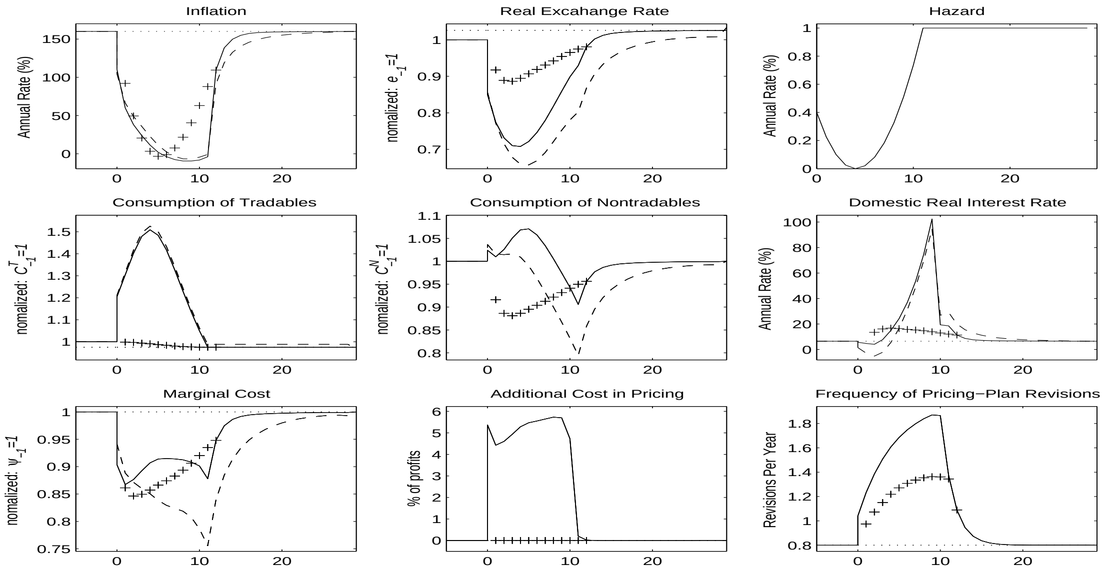



Figure 3: Temporary Disinflation Programs

The temporary ERB (MB) disinflation program consists in a reduction of the depreciation rate (money growth rate) from 160 to 10 percent per year for 12 quarters, restoring its high level thereafter. The solid line (—) shows the equilibrium path with state-dependent nominal rigidities. The dashed line (− −) shows the special case with constant nominal rigidities. The parameter values are those in Table 1.

(a) Exchange Rate-Based Disinflation with Uncertain Duration




(b) Moned-Based Disinflation with Uncertain Duration

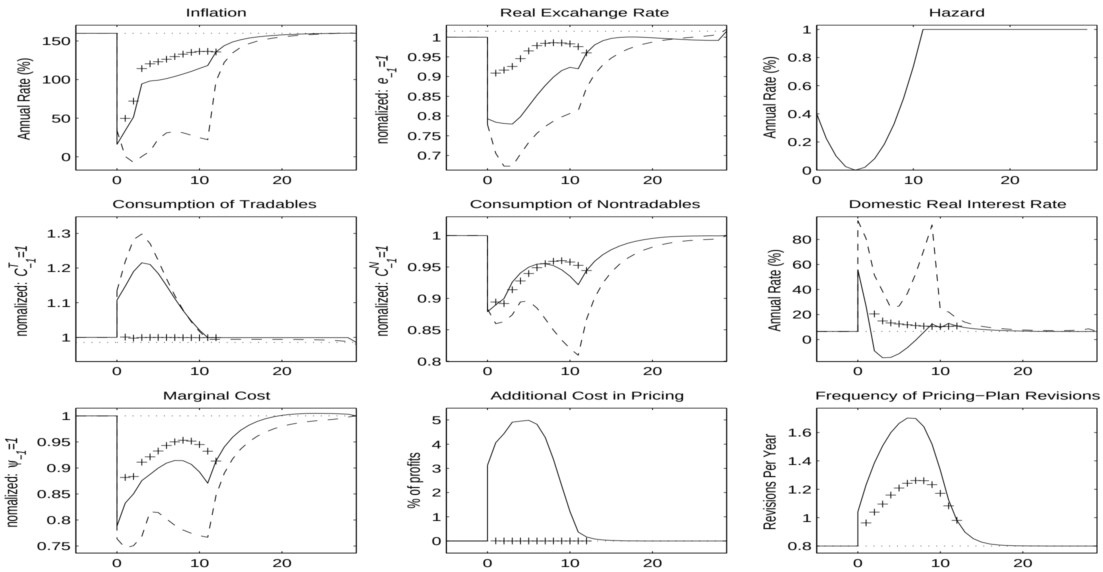
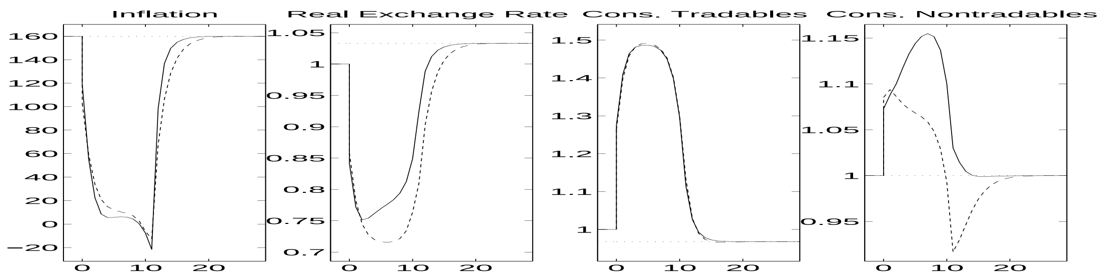


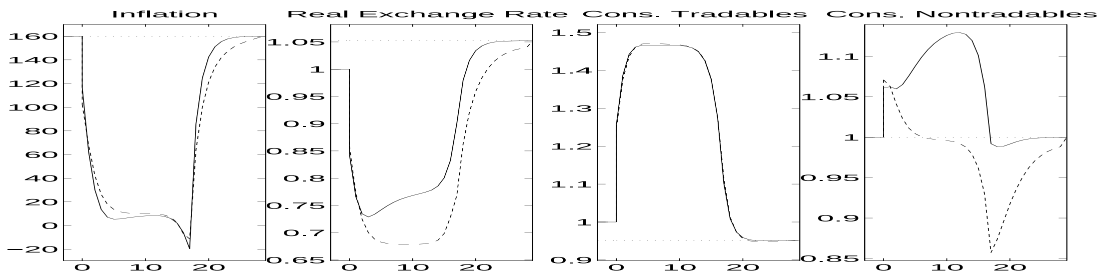

Figure 4: Disinflation Programs with Uncertain Duration

The ERB (MB) disinflation program consists in a reduction of the depreciation rate (money growth rate) from 160 to 10 percent per year, which agents perceive as of uncertain duration. The hazard function in the upper right panel shows the probability of the exchange rate depreciation (money growth rate) taking a value of 160 percent in $t+1$ conditional on been 10 percent at $t$. The solid line (—) shows the model with state-dependent nominal rigidities for a program lasting at most 12 quarters. The mark $(+)$ shows the alternative value at $t$ of the corresponding variable if the program is abandoned at $t$ (the remaining path under such state is not shown). The dashed line $(--)$ shows the equilibrium path with constant nominal rigidities. The calibration assumes $\varphi = 0$. All other parameter values are those in Table 1.

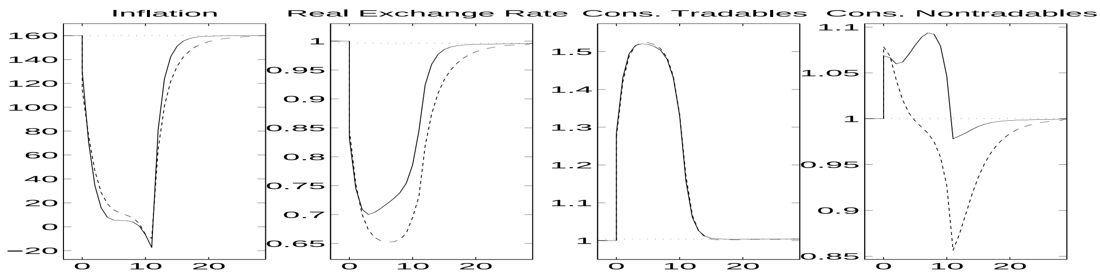
(a) Lower Degree of Nominal Rigidities: $(1 - \alpha_L) = 0.3$, $(1 - \alpha_H) = 0.7$




(b) Longer Time Duration: $\tau = 18$




(c) High Elasticity of Money Demand: $\varsigma = 0.5$




(d) Logarithmic Utility in Labor: $\zeta = 1$

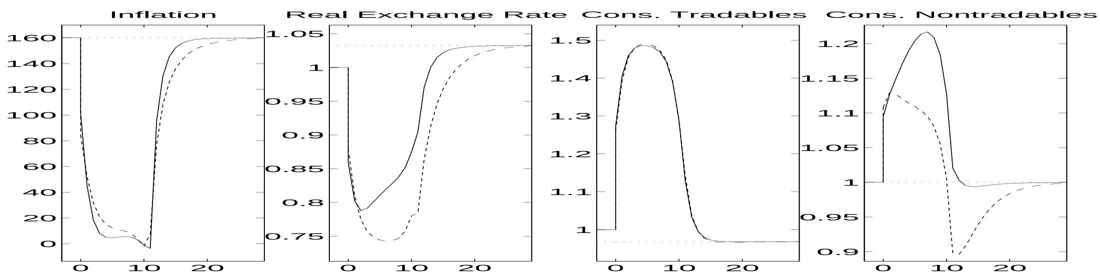
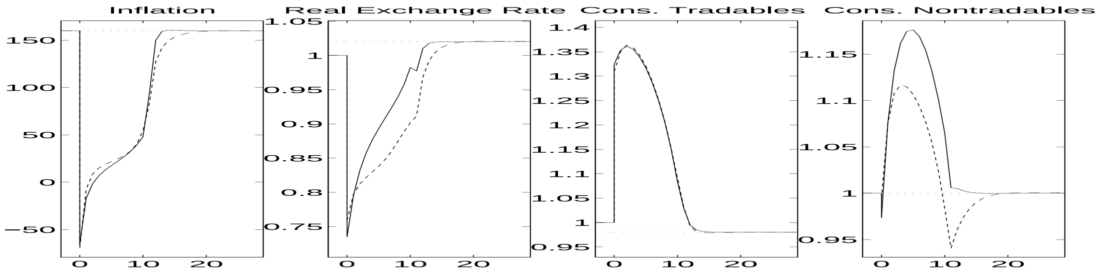


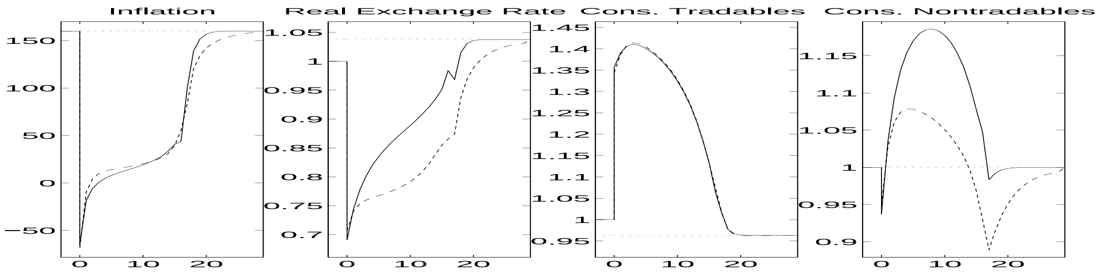

Figure 5: Sensitivity Analysis for ERB Disinflations

Sensitivity analysis for temporary ERB disinflations. The solid line (—) shows the equilibrium path with state-dependent nominal rigidities. The dashed line ($--$) shows the special case with constant nominal rigidities. The parameter values are those in Table 1, except for the corresponding parameter indicated above.

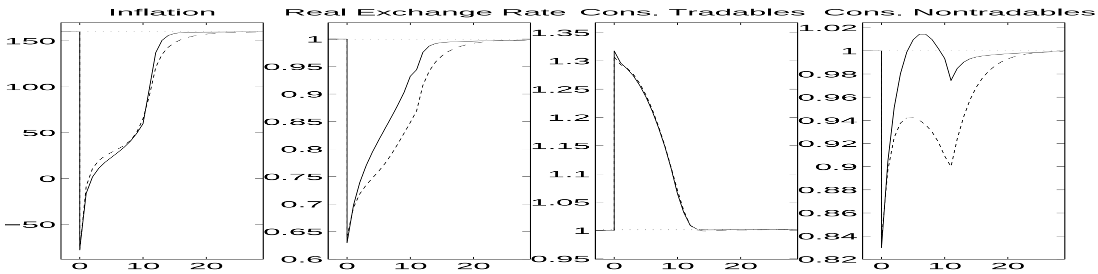
(a) Lower Degree of Nominal Rigidities: $(1-\alpha_L)=0.3$, $(1-\alpha_H)=0.7$




(b) Longer Time Duration: $\tau = 18$




(c) High Elasticity of Money Demand: $\varsigma = 0.5$




(d) Logarithmic Utility in Labor: $\zeta = 1$

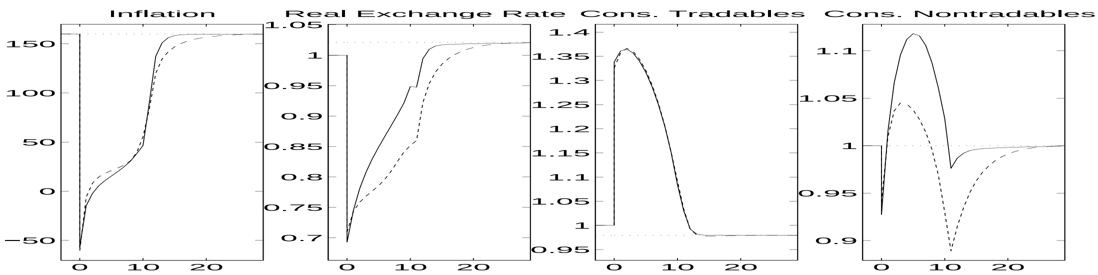



Figure 6: Sensitivity Analysis for MB Disinflations

Sensitivity analysis for temporary MB disinflations. The solid line (—) shows the equilibrium path with state-dependent nominal rigidities. The dashed line ($--$) shows the special case with constant nominal rigidities. The parameter values are those in Table 1, except for the corresponding parameter indicated above.