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

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Abstract

Experiences of high-inflation economies suggest that exchange rate-based (ERB) and money-based (MB) disinflations induce sharply different dynamics in consumption and GDP. I study the role of nominal rigidities to explain such dynamics. I build on Calvo pricing to introduce elements of state-dependent into an otherwise standard small open economy. This new feature delivers state-dependent nominal rigidities (SDNR). Nonlinear simulations show that the model with SDNR generates a dynamic behavior consistent with both ERB and MB disinflations; however the models special case with constant nominal rigidities is not successful rationalizing ERB disinflations.

Keywords: Nominal rigidities, disinflations, state-dependent pricing, exchange-rate based stabilizations

JEL classification: E31, E32, E37

Resumen

Experiencias de economías con alta inflación sugieren que las desinflaciones basadas en el tipo de cambio y las basadas en dinero doméstico, inducen dinámicas de consumo y PIB bastante diferentes. Extiendo el modelo de determinación de precios de Calvo, el cual supone que las empresas cambian precios con una frecuencia exógena, para hacer que la frecuencia de cambios de precio sea endógena. Aplico este modelo de precios a una economía pequeña y abierta. Simulaciones no lineales de la economía muestran que el consumo sigue patrones consistentes con ambos tipos de desinflaciones. Sin embargo, el modelo con frecuencia de cambios de precios exógena no es exitoso para explicar las desinflaciones basadas en el tipo de cambio.

Palabras clave: Rigidez nominal, desinflación, precios dependientes del Estado, estabilizaciones basadas en el tipo de cambios

Clasificación JEL: E31, E32, E37

STATE-DEPENDENT NOMINAL RIGIDITIES & DISINFLATION PROGRAMS IN SMALL OPEN ECONOMIES

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Resumen

Experiencias de economías con alta inflación sugieren que las desinflaciones basadas en el tipo de cambio y las basadas en dinero doméstico, inducen dinámicas de consumo y PIB bastante diferentes. Extiende el modelo de determinación de precios de Calvo, el cual supone que las empresas cambian precios con una frecuencia exógena, para hacer que la frecuencia de cambios de precio sea endógena. Aplico este modelo de precios a una economía pequeña y abierta. Simulaciones no lineales de la economía muestran que el consumo sigue patrones consistentes con ambos tipos de desinflaciones. Sin embargo, el modelo con frecuencia de cambios de precios exógena no es exitoso para explicar las desinflaciones basadas en el tipo de cambio.

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 recession². On the other hand, MB programs are accompanied by an initial short-lived recession followed by a recovery (see Calvo and Végh, 1999).

In models with nominal rigidities, the gradual response of nominal prices to monetary policy 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 expansionary phase of ERB disinflations.

In models of ERB disinflations we often find that inflation acts as a distortionary tax on the relative price of consumption and leisure—for example, as a result of a cash-in-advance constraint—, 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. Moreover, in models with flexible prices the inflation-output trade-offs consistent with MB disinflations are not present.

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

²See for example Figure 2 that shows the 1987 Mexican ERB disinflation and the discussion in section 3.

Thus, the paper adds to two branches of literature. On one hand, it contributes to the growing research that following Dotsey, King, and Wolman (1999) studies the effects of state-dependent pricing (and therefore the effects of state-dependent nominal rigidities) in business cycle fluctuations— see for example Burstein (2005), Golosov and Lucas (2003) and Devereux and Siu (2005). On the other hand, the paper contributes to the literature of large disinflation programs, which recently has focused on ERB disinflations—see for example Uribe (2002) and references therein.

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, the rate at which nominal prices incorporate changes in the state of the economy is constant and exogenous.

Ireland (1997) is the first to point out the role of endogenous nominal rigidities in the context of MB disinflations in closed economies. Ireland (1997) shows that when the economy faces large and fast disinflations, firms find optimal to speed up price revisions; in turn, faster price changes imply that the size of the recession associated to large MB disinflations may be small. However, small disinflations may result costly if prices adjust slowly.

In this paper a similar mechanism helps to rationalize the sustained expansion in consumption associated to ERB disinflation programs. When the economy faces large ERB disinflations, firms have an incentive to increase the speed of optimal price revisions, which reduces the adverse effects on output. Additionally, when this is supplemented with an income effect coming from the reduction of the distortionary tax, the net effect is a sustained expansion in consumption of tradables and non-tradables.

However, when the disinflation is MB, as in Uribe (1999) or Ireland (1997), there is an initial liquidity crunch in the economy that induces a recession despite of the income effect and despite faster price revisions, as long as prices do not fully adjust when the program is implemented.³

Different from Ireland (1997), the pricing scheme in this paper exploits recent devel-

³See section 4.1 for details.

opments in the state-dependent pricing literature by Dotsey, King, and Wolman (1999). Moreover, I focus not only on MB disinflations but mainly on ERB disinflations.

The pricing scheme assumes, as in Calvo (1983), 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 drawn randomly. A firm chooses a higher probability of pricing-plan revisions if the cost of doing so is compensated by the associated change in the value of the firm.

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

Using nonlinear simulations I study the dynamics of key macroeconomic variables under three disinflation scenarios. The first experiment is a permanent and credible disinflation program; this experiment illustrates the basic dynamics of ERB and MB disinflations. 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 only τ quarters, after which 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.

The key finding of the paper can be illustrated in a temporary ERB program that last for twelve quarters. The model with state-dependent nominal rigidities (SDNR from here on), calibrated with plausible parameters, predicts that, as long as the program is in place, firms are willing to spend between five and six percent of their profits to implement faster pricing-plan revisions; at the macroeconomic level, that implies that the economy faces a gradually lower degree of nominal rigidities. In turn, that gives room for a sustained expansion in the consumption of tradables—i.e., the sector with

nominal rigidities—followed by a later recession. The expansion reaches its peak eight quarters after the implementation of the program. In contrast, in the model’s special case of time-dependent pricing, counterfactually, the recession sets forth immediately after the beginning of the program.

Those qualitative discrepancies across the model with SDNR and its special case of constant nominal rigidities also hold when we account for uncertainty in the duration of the program (i.e. the program can be abandoned with a positive probability) and they are robust to alternative calibrations. 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.

On the other hand, in temporary MB disinflations or MB programs with uncertain duration, the model with SDNR and its special case, they both predict an initial short-lived recession in nontradables. Moreover, the transition dynamics of both models are qualitatively 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 mechanism and the optimal decision for firms in the nontradable sector, that is, the sector with nominal rigidities. Section 3 describes in more detail features of the data associated to ERB disinflations and calibrates the model. Section 4 discusses numerical simulations of the three stabilization programs studied, including a subsection with sensitivity analysis. Section 5 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 introduce uncertainty in the subsection 4.3.

Assume that the law of one price holds for internationally tradable goods. This is,

$P_t^T = \mathcal{E}_t P_t^{T*}$ in any period $t = 0, 1, 2, \dots$, where P_t^T and P_t^{T*} denote the nominal price of tradables in the domestic and foreign economies respectively, and \mathcal{E}_t is the nominal exchange rate. Moreover, normalizing the foreign price of tradables to one, the law of one price implies $P_t^T = \mathcal{E}_t$.

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, $e_t = \mathcal{E}_t / P_t^N$. 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

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

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

2.1. The Household

The representative household derives utility from leisure and from the 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

$$U(C_t, N_t) \equiv \ln(C_t - \varphi C_{t-1}) + \frac{\kappa}{1 - \zeta} (1 - n_t)^{1 - \zeta}, \quad (2)$$

where $\zeta > 0, \varphi \in [0, 1)$ 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,⁴ however $\varphi = 0$ corresponds to the more conventional case of time separability in consumption.

⁴Uribe (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

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

where $\gamma \in (0, 1)$ and $C_t^N \equiv \left[\int_0^1 [c_t^N(z)]^{(\theta-1)/\theta} dz \right]^{\theta/(\theta-1)}$ 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 Δ_t . The budget constraint in terms of tradables is

$$\frac{W_t n_t}{e_t} + Y^T + a_t + \frac{\Delta_t}{e_t} + \frac{M_{t-1}}{e_t} + b_{t-1}(1+r) \geq \left(C_t^T + \frac{\int_0^1 p_t^N(z) c_t^N(z) dz}{e_t} \right) (1 + s(u_t)) + b_t + \frac{M_t}{e_t}.$$

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 that are a proportion $s(\cdot)$ of consumption expenditure, 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

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

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

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

where $m_t \equiv M_t / \mathcal{E}_t$ are real money balances in terms of tradables.

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

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

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 $t = 0, 1, 2, \dots$, to maximize

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

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:

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

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

Let χ 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:

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

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 $(u_t)^2 \cdot s_u(u_t) = i_t / (1 + i_t)$, which, from the transaction costs technology (4) and the money velocity (5),

implies the money demand:

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

The first-order condition for labor (n_t) implies

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

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 (1983) pricing, I assume that the continuum of firms in any period t can be described by two disjoint sets of firms— μ and V —that are subject to a set-specific Calvo probability to reset pricing plans. The set μ , with mass μ_t in period t , contains firms that reset prices subject to the probability $(1 - \alpha_L)$. The set V , with mass V_t in period t , is formed by firms that change prices subject to the probability $(1 - \alpha_H)$; without loss of generality I assume $(1 - \alpha_H) > (1 - \alpha_L)$. It follows that $\mu_t + V_t = 1$ for all t . As described below (p. 14), the mass of both sets is endogenously determined in every period by the optimal pricing plan of firms (see Figure 1).

A *pricing plan* consists of three objects: a nominal price for the firm's product, a constant growth rate for that price, and a *Calvo probability* $(1 - \alpha_j) \in \{(1 - \alpha_L), (1 - \alpha_H)\}$. The Calvo probability dictates how often, in average, a firm resets pricing plans; in particular, the firm can choose a new pricing plan only when it receives a random signal that arrives with probability $(1 - \alpha_j)$.

Once a firm receives the random signal to change its pricing plan, as in Dotsey, King and Wolman (1999), it also observes the realization of the random cost $\xi \geq 0$ that the firm has to pay to increase its Calvo probability. The random cost ξ is measured in

units of nontradable output.

If the firm does not pay the random lump-sum cost ξ , 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 ⁵.

A firm paying the random cost ξ at t' is subject to the Calvo probability $(1 - \alpha_H)$ 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 $(1 - \alpha_L)$.

[Figure 1 about here.]

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

A firm choosing a new pricing plan at t' maximizes the value of the firm by choosing the triplet $\{(1 - \alpha_j), p_{j,t'}^{N^*}(z), \omega_{j,t'}(z)\}$. Moreover, during the lapse in which the firm does not optimally choose pricing plans it adjusts the price charged at a constant rate; that is, the price of a firm with Calvo probability $(1 - \alpha_j)$, evolves according to:

$$p_{j,t'+s}^N(z) = [\omega_{j,t'}(z)]^s p_{j,t'}^{N^*}(z), \quad \text{for } s = 0, 1, 2, \dots \quad (13)$$

The role of indexation is twofold. As in the hybrid time-dependent and state-dependent pricing model of Burstein (2005) or as in the time-dependent pricing model of Calvo et al. (2003), it generates inflation inertia. In this paper, indexation also allows to calibrate the model to high levels of steady-state inflation.

⁵In Dotsey et al. (1999) firms *evaluate* in each period their pricing policies; 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. In this paper firms *evaluate* pricing policies only infrequently.

The value of the firm

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 the firm is choosing a new pricing-plan in that period and selects the Calvo probability $(1 - \alpha_j)$, for $j = H, L$. The other two recursions are associated to the value of the firm at $t' + s$, $D_{1,j,t'+s}$, for $s = 1, 2, 3, \dots$ and $j = H, L$, given that the firm 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.

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 $d(p_{j,t}^N(z), \cdot) \equiv \Delta_t(z) / P_t^N$ 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

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

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 $\lambda_{t'+1}$ ⁶.

⁶Note that the firm faces idiosyncratic randomness in the random lump-sum cost, however it will become

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 $d(p_{H,t'}^{N^*}(z), \cdot)$ 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 α_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 $s = 1, 2, 3, \dots$, acting under $(1 - \alpha_j)$, if it has not received the signal of pricing-plan revisions since t' , is ⁷:

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

Optimal pricing plan I: Optimal Calvo Probability

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 at t' under $(1 - \alpha_H)$ exceeds

clear later that firms can have perfect foresight of the aggregate variables.

⁷Note that the maximization operator does not appear in (15) because the only decision 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.

the value of the firm at t' under $(1 - \alpha_L)$ by at least the random cost associated ξ , this is, if and only if

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

Recall that the all variables in (16) are in units of nontradable output. Moreover, assume that ξ has a cumulative density function $G(\cdot)$. Thus, before observing the realization of ξ , the probability of z choosing $(1 - \alpha_H)$ is given by $\Pr [D_{0,H,t'} - D_{0,L,t'} \geq \xi] = G(D_{0,H,t'} - D_{0,L,t'})$.

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

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

For parameterization purposes assume $g(\cdot) \equiv \iota \exp(-\iota \xi)$ if $\xi \geq 0$, with $\iota > 0$, and $g(\cdot) \equiv 0$ if $\xi < 0$.⁸ Then, the density function of the random lump-sum cost, implies:

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

and the conditional expected lump-sum cost is⁹

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

⁸Different from Dotsey et al. (1999) or Burstein (2005), I do not need to impose an upper bound for the random variable ξ . This is because firms can choose not to pay the random cost and still change prices, but with a lower frequency.

⁹Note that the expected random lump-sum cost is conditional on ξ 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 $1/G(D_{0,H,t'} - D_{0,L,t'}) \cdot \int_0^{[D_{0,H,t'} - D_{0,L,t'}]} x g(x) dx$. Thus the term $1/\lambda_t$ in (18) is part of the conditional distribution.

Optimal pricing plan II: Optimal Pair $(p_{j,t'}^{N*}(z), \omega_{j,t'}(z))$

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

$$y_t^N(z) = n_t(z), \quad (19)$$

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

Constant returns to scale imply that the total cost of production required to meet consumer demand can be written as $\psi_t y_{c,t}^N(z)$, where ψ_t is the real marginal cost in terms of nontradables.¹⁰ 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:

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

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

Using the recursions for the value of the firm (14) and (15), the profit function (20) and the time-dependent rule (13), I obtain from the first-order conditions that the optimal pair $(p_{j,t'}^{N*}(z), \omega_{j,t'}(z))$ satisfies

$$\frac{p_{j,t'}^{N*}}{P_{t'}^N} = \frac{\theta}{\theta - 1} \frac{\sum_{s=0}^{\infty} \Omega_{t',t'+s} (\alpha_j)^s (\omega_{j,t'}^{-\theta})^s \left[\prod_{j=1}^s \pi_{t'+j} \right]^\theta C_{t'+s}^N \psi_{t'+s}}{\sum_{s=0}^{\infty} \Omega_{t',t'+s} (\alpha_j)^s (\omega_{j,t'}^{(1-\theta)})^s \left[\prod_{j=1}^s \pi_{t'+j} \right]^{(\theta-1)} C_{t'+s}^N} \quad (21)$$

and

¹⁰Marginal cost is not firm specific because labor is freely mobile.

$$\frac{p_{j,t'}^{N*}}{P_{t'}^N} = \frac{\theta}{\theta - 1} \frac{\sum_{s=0}^{\infty} s \Omega_{t',t'+s} (\alpha_j)^s (\omega_{j,t'}^{-\theta})^s \left[\prod_{j=1}^s \pi_{t'+j} \right]^\theta C_{t'+s}^N \Psi_{t'+s}}{\sum_{s=0}^{\infty} s \Omega_{t',t'+s} (\alpha_j)^s (\omega_{j,t'}^{(1-\theta)})^s \left[\prod_{j=1}^s \pi_{t'+j} \right]^{(\theta-1)} C_{t'+s}}, \quad (22)$$

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

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Equations (21) and (22) resemble the conditions obtained in the 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.

A recursion for the average frequency of pricing-plan revisions

To aggregate firm-level prices we need to keep track of the mass of firms setting prices under each Calvo probability. Recall that V_t is the mass of firms setting prices with the Calvo probability $(1 - \alpha_H)$ and μ_t is the mass of firms setting prices subject to the Calvo probability $(1 - \alpha_L)$ —see Figure 1. Thus the mass of firms choosing the Calvo probability $(1 - \alpha_H)$ at time t is $V_t - V_{t-1}$. It follows that the evolution of V_t and μ_t can be described with the recursions:

$$\begin{aligned} V_t &= V_{t-1} + \lambda_t(1 - \alpha_L)\mu_{t-1} - (1 - \lambda_t)(1 - \alpha_H)V_{t-1} \\ \mu_t &= 1 - V_t, \\ \mu_{-1} &= \mu, \text{ and } V_{-1} = V. \end{aligned} \quad (23)$$

The first recursion in (23) 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

¹¹Note that from the definition of $\omega_{t'}$ it follows that $\Omega_{t',t'+s} = \prod_{j=1}^s \frac{(1+r)\varepsilon_{t'+j}}{\pi_{t'+j}}^{-1}$ with $\Omega_{t',t'} \equiv 1$. Also note that I use the notation $\prod_{j=1}^0 (\cdot) \equiv 1$.

the beginning of the period, minus the mass of firms switching back from $(1 - \alpha_H)$ to $(1 - \alpha_L)$ ¹²; the second equation in (23) holds because the mass of firms is constant and equal to one, so that $V_t + \mu_t = 1$ for all $t = 0, 1, 2, \dots$; and the initial conditions are determined by the steady state of the economy.

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

$$F_t \equiv (1 - \alpha_L)\mu_t + (1 - \alpha_H)(1 - \mu_t) \quad (24)$$

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

Thus, the Calvo probabilities in this model can be interpreted as an upper and lower bound to the *aggregate degree of nominal rigidities*, measured by F_t . Moreover, the aggregate degree of nominal rigidities fluctuates with the state of the economy.

The price level

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

$$P_t^N \equiv \left[\mu \left(P_{L,t}^N \right)^{1-\theta} + (1 - \mu) \left(P_{H,t}^N \right)^{1-\theta} \right]^{\frac{1}{1-\theta}} \quad (25a)$$

with $P_{L,t}^N \equiv \left[\frac{1}{\mu} \int_0^{\mu} [p_t^N(\mathfrak{z})]^{1-\theta} d\mathfrak{z} \right]^{\frac{1}{1-\theta}}$ and $P_{H,t}^N \equiv \left[\frac{1}{1-\mu} \int_{\mu}^1 [p_t^N(\mathfrak{z})]^{1-\theta} d\mathfrak{z} \right]^{\frac{1}{1-\theta}}$. The index $\mathfrak{z} \in [0, 1]$ is chosen so that the integral in the sub-index $P_{j,t}^N$ aggregates prices of firms 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 ex-

¹²Thus, the second term in the first recursion states that, at time t , a fraction λ_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 $(1 - \alpha_L)$.

pressed as a weighted average of prices optimally chosen in the past—weighted by α_j . However, different from time-dependent pricing models, the mass of firms setting a new pricing policy subject to $(1 - \alpha_j)$ changes with the state of the economy. Accordingly, we can express the price sub-indexes as:

$$(P_{L,t}^N)^{1-\theta} = \frac{1}{\mu} \sum_{s=0}^{\infty} (\alpha_L)^s \cdot SD_{L,t,s} \cdot \left[p_{L,t-s}^{N*} (\omega_{L,t-s})^s \right]^{1-\theta} \quad (25b)$$

and

$$(P_{H,t}^N)^{1-\theta} = \frac{1}{1-\mu} \sum_{s=0}^{\infty} (\alpha_H)^s \cdot SD_{H,t,s} \cdot \left[p_{H,t-s}^{N*} (\omega_{H,t-s})^s \right]^{1-\theta}, \quad (25c)$$

where the terms $SD_{L,t,s} \equiv [(1 - \alpha_L)\mu_{t-s-1} - (V_{t-s} - V_{t-s-1})]$ and $SD_{H,t,s} \equiv [(1 - \alpha_H)(1 - \mu_{t-s-1}) + (V_{t-s} - V_{t-s-1})]$ capture the effects of (elements of) state-dependent pricing on the price index ¹³.

Calvo price index as special case

The price index described by (25a), (25b) and (25c) 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 choose the higher Calvo probability is sufficiently high, such that firms keep the low Calvo probability under any state of the economy; then, from the condition (16) it follows that $\lambda_t = 0$ for all t , and from the recursions in (23) it follows that $\mu_t = \mu = 1$ and $V_t = V = 0$ for all t ¹⁴. Moreover, $SD_{H,t,s} = 0$ for all t in equation (25c) and $SD_{L,t,s} = (1 - \alpha_L)$ for all t in equation

¹³In the sub-index $P_{L,t}^N$ above, the mass of firms setting the new pair $p_{L,t-s}^{N*}, \omega_{L,t-s}$ 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 $p_{H,t-s}^{N*}, \omega_{H,t-s}$ 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, $(V_{t-s} - V_{t-s-1})$.

¹⁴In numerical simulations, a high enough mean of the random cost (e.g. $E[\xi] = 1/\iota = 1e^3$) produces $\lambda_t \approx 0 \forall t$, $\mu_t \approx 1$ and $V_t \approx 0 \forall t$ as shown in the next section.

(25b); thus, the price indexes (25a)-(25c) boil down to:

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

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 $\rho_t \equiv M_t/M_{t-1}$ and makes lump-sum transfers a_t . The consolidated budget constraint of the government, in terms of tradables, is

$$b_{g,t-1}(1+r) + \frac{M_t - M_{t-1}}{\varepsilon_t} = b_{g,t} + a_t, \quad (26)$$

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

$$m_t = \frac{\rho_t}{\varepsilon_t} m_{t-1}. \quad (27)$$

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 $\{\rho_t\}_{t=0}^{\infty}$ in the context of policy experiments in the section 4. Appendix A states a formal definition of equilibrium for the economy and its characterization as a system of equations.

3. Regularities of ERB Disinflations & Calibration

Mexico's 1987 ERB Disinflation

Empirical regularities associated to ERB disinflations are extensively documented for example in Végh (1992) or Calvo and Végh (1993, 1999). To illustrate some of those empirical regularities it is instructive to review the macroeconomic patterns of the Mexican ERB disinflation¹⁵. The Mexican ERB disinflation program was announced on December of 1987 but initialized in the first quarter of 1988 and finally it was abandoned in the last quarter of 1994.

[Figure 2 about here.]

Figure 2 plots the quarterly series of annual inflation, real exchange rate (Mexican pesos per US dollar), private consumption, GDP, trade balance and nontradable output. All series are in real pesos of 1993, seasonally adjusted and except for inflation and real exchange rate, the series are detrended. Also, except for inflation (in annual rate) and trade balance (in billions of pesos), the series are normalized to one in the last quarter of 1987 ($t=-1$). The horizontal axis measures the number of quarters after 1988.1. Figure 2 illustrates four characteristics associated to ERB disinflations:

- i) When the program is put in place, private consumption gradually rises to achieve its peak *twenty quarters* after the implementation of the program with a level 15 percent above its value in 1987.4. Another example of this pattern in consumption is shown in Figure 1 in Uribe (2002) for the Argentine Convertibility Plan of 1991; in that figure consumption expansion peaks about 12 quarters after the implementation of the program with a level 35 percent above its value at the beginning of the program.
- ii) The boom-recession cycle of private consumption is also present in nontradables, tradables and GDP. Figure 2 shows that nontradable output, trade balance and

¹⁵Those patterns are also present in several other ERB disinflation episodes such as the 1991 Convertibility Plan of Argentina studied in Uribe (1999); the stabilization programs of Argentina, Chile and Uruguay in the late 1970s studied in Rebelo and Végh (1995); and the plans of the mid-1980s in Argentina, Israel and Brazil studied in Reinhart and Végh (1995), among others.

GDP follow patterns similar to the one for private consumption. In particular, the peak in nontradables and GDP is achieved around 20 quarters into the program.

- iii) Inflation falls gradually. In Figure 2 inflation falls from an annual rate of 170 percent to 17 percent in six quarters and reaches 7 percent before the abandonment of the program.
- iv) The real exchange rate appreciates gradually for most of the duration of the program. In the first six quarters of the program, the real exchange rate of the Mexican peso versus the US dollar (in pesos per dollar) drops 30 percent of its value in 1987.4.

Calibration

Following Mendoza and Uribe (1997), most of the parameter values that I use to calibrate the model roughly correspond to the 1987 Mexican ERB disinflation. The baseline parameter values are summarized in Table 1.

[Table 1 about here.]

Preferences. The discount factor ($\beta = 0.984$) implies an annual real rate of return of 6.5 percent; the elasticity of the consumption aggregator with respect to tradables is $1/2$ ($\gamma = 0.5$), which implies a steady-state share of tradables in total consumption of $1/2$; the own-price elasticity of nontradables ($\theta = 6$) implies a steady-state markup of 20 percent above marginal cost; the value of κ in the utility function is chosen such that in the pre-program 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 ($1/\zeta$) is set to $1/3$; as in Uribe (2002) there is habit formation in consumption with $\varphi = 0.5$, however I also analyze the case of $\varphi = 0$ in the section 4.3.

Transaction costs. The elasticity of money demand with respect to $i_t/(1 + i_t)$ ($1/\sigma = 0.2$) is set to 0.2 consistent with empirical estimates in Reinhart and Végh (1995) or Kamin and Rogers (1996); following Mendoza and Uribe (1997), the value of K in the

transaction costs technology is chosen such that in the pre-stabilization steady-state money velocity is 0.32 ($K = 3.8$)¹⁶; the endowment of tradables is set to 1/3 ($Y^T = 1/3$) and the initial stocks of bonds are set to zero.

Pricing mechanism. 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; $(1 - \alpha_L) = 0.2$ implies that firms subject to the lower Calvo probability set new pricing policies once every five quarters on average, and $(1 - \alpha_H) = 0.5$ implies that, under the higher Calvo probability, firms revise pricing policies twice per year on average. In line with Dotsey, King and Wolman's (1999) calibration, the parameter ι in the distribution of the random cost implies an unconditional expected cost of 0.005 units of nontradable output ($E(\xi) = 1/\iota = 0.005$). In each experiment I also simulate the special case of the model that boils down to the time-dependent price index proposed in Calvo et al. (2003). To do that, I set the unconditional expected random lump-sum cost to 1,000 units of nontradable output (see p. 16).

Note that $(1 - \alpha_L)$ is the only relevant Calvo probability for the special case of the model; for the special case, the benchmark calibration implies that firms change pricing policies every fifteen months on average. 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. In subsection 4.4, I perform sensitivity analysis by assuming that firms change pricing-policies every 8.4 months on average for the special case of the model.

Solution Algorithm. I solve the model using an iterative backward recursion algorithm¹⁷. That method is used for example by Golosov and Lucas (2003) or Burstein

¹⁶ Note that substituting the money demand (11) into the money velocity (5) yields the money velocity as a function of the nominal interest rate: $u_t = K^{-\frac{1}{\sigma}} i_t / (1 + i_t)^{1/\sigma}$. I choose the value of K so that U takes a convenient steady-state value.

¹⁷The algorithm assumes that there is a period $t = T$ when the economy reaches a new steady state after the implementation of the program. i) I make an initial guess for the path of the aggregate variables

(2005) for state-dependent pricing models for closed economies and by Mendoza and Uribe (1997) for an open economy with flexible prices ¹⁸.

4. Disinflation Programs

4.1. Permanent and Credible Disinflation

A permanent and credible ERB disinflation program is defined as a reduction of the exchange rate depreciation from ε^h to ε^l , which occurs in $t = 0$. That is: $\varepsilon_t = \varepsilon^h$ for $t < 0$ and $\varepsilon_t = \varepsilon^l$ for $t \geq 0$, where $\varepsilon^h > \varepsilon^l$. Similarly, in a permanent and credible MB disinflation program the monetary authority reduces the money growth rate from ρ^h to ρ^l in $t = 0$. That is: $\rho_t = \rho^h$ for $t < 0$ and $\rho_t = \rho^l$ for $t \geq 0$, where $\rho^h > \rho^l$. I calibrate the programs with an initial inflation rate of 160 percent per year ($\varepsilon^h = \rho^h = 1.27$) and a low inflation rate of 10 percent per year ($\varepsilon^l = \rho^l = 1.024$).

[Figure 3 about here.]

Figure 3 displays the dynamics of permanent ERB and MB programs. Panel 3(a) shows that the ERB program generates a sustained boom in consumption of tradables and nontradables. The source of the expansion is the wealth effect of lower nominal interest rates. To see this, rewrite the transaction costs as an increasing function of the nominal interest rate ¹⁹: $s(\cdot) = K^*(i_t/(1 + i_t))^{(\sigma-1)/\sigma}$, where $K^* \equiv K^{1/\sigma}/(\sigma - 1)$; thus lower interest rates relax the budget constraint (6). Moreover, to simplify assume $\varphi = 0$ and use the last result together with equations (9) and (12) to obtain the marginal rate of substitution between leisure and consumption of tradables:

$\{C_t^N, \pi_t, \psi_t\}_{t=0}^\infty$; given that guess, ii) I solve the firm-level prices $\{p_{j,t}^{N*}/p_t^N, \omega_{j,t}\}_{t=0}^\infty$ from the system (21)-(22) and iii) I use those firm-level prices to aggregate prices, and together with the household's first-order conditions and budget constraints I 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. A detailed appendix is available under request.

¹⁸Golosov and Lucas (2003) study credible and noncredible permanent disinflation programs under perfect foresight (among other experiments) in a state-dependent pricing model for a closed economy. Burstein (2005) introduces price indexation in a state-dependent pricing model to show that it generates inflation inertia. He also shows that inflation and output respond asymmetrically to monetary expansions and contractions. This last point is studied more intensively by Devereux and Siu (2005).

¹⁹To obtain the equation above use the result in footnote 16 and the transaction costs (4).

$-\frac{u_{cT}}{u_{(1-n_t)}} = \frac{1+\sigma K^* \left(\frac{i_t}{1+i_t}\right)^{(\sigma-1)/\sigma}}{w_t}$. Then, a disinflation program also reduces the distortion in the “effective price of consumption” by lowering the nominal interest rate.²⁰

Panel 3(b) shows that the MB program yields an initial short-lived recession in the nontradable sector. The contraction is due to a liquidity crunch at the beginning of the program; that is, lower inflation expectations increase money demand but this cannot be accommodated neither by money supply nor by the price level (prices adjust gradually) producing a recession in the nontradable sector. To see this, rewrite the money demand (11) in terms of nontradables and use the first-order condition (10) to obtain: $M_t/P_t^N = \frac{K^{1/\sigma}}{(1-\gamma)} C_t^N (i_t/(1+i_t))^{-1/\sigma}$; then, lower interest rates increase money demand. However recall that in a MB program the money supply obeys: $M_t = \rho_t M_{t-1}$. It follows that in time zero: $\rho^1 M_{-1}/P_0^N = \frac{K^{1/\sigma}}{(1-\gamma)} C_0^N (i_0/(1+i_0))^{-1/\sigma}$, when ρ falls to ρ^1 and prices do not fully accommodate the shock (since there is a fraction of firms not adjusting prices), C_0^N must fall²¹.

On the contrary, ERB programs do not generate a liquidity crunch because changes in money demand have to be accommodate by money supply (ρ_t is endogenously determined). Note that a permanent and credible ERB program generates a sustained expansion in real activity, however it does not produce a recession after the expansion. To explain the boom-recession cycle Calvo (1986) proposes the introduction of lack of credibility. I explore this in the next two experiments.

4.2. Temporary Disinflation

As pointed out by Calvo and Végh (1999), imperfect credibility is a common characteristic of stabilization programs. 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 ERB disinflation the monetary authority reduces the depreciation rate from ε^h to ε^l for τ quarters. That is: $\varepsilon_t = \varepsilon^h$ for $t < 0$, $\varepsilon_t = \varepsilon^l$ for $t = 0, 1, \dots, \tau - 1$, and $\varepsilon_t = \varepsilon^h$ for $t \geq \tau$. Similarly, in a temporary MB disinflation

²⁰The effect of the distortion in the effective price of consumption still takes place even if we eliminate the direct effect on the budget constrain.

²¹Clearly, the size of the initial recession crucially depends on initial degree of nominal rigidities and on the elasticity of demand. I perform robustness analysis on this parameters in subsection 4.4.

program the monetary authority reduces the money growth rate from ρ^h to ρ^l for τ quarters. That is: $\rho_t = \rho^h$ for $t < 0$, $\rho_t = \rho^l$ for $t = 0, 1 \dots, \tau - 1$, and $\rho_t = \rho^h$ for $t \geq \tau$. The ERB and MB temporary programs are calibrated with $\varepsilon^h = \varphi^h = 1.27$, $\varepsilon^l = \varphi^h = 1.024$ and $\tau = 12$.²²

[Figure 4 about here.]

Figure 4(a) captures the main result of the paper. In ERB temporary disinflations, the model with SDNR (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 12-quarter program. In contrast, in the special case of constant nominal rigidities (dashed line) the peak of the expansion in nontradables occurs in the first quarter of the program; the recession in nontradables sets forth immediately after the announcement of the program.²³

At the microeconomic level, Figure 4(b) shows that, for the duration of the program, firms are willing to spend around five percent of their profits to speed up optimal pricing²⁴; that implies that (Figure 4(a)) the frequency of optimal price-revisions grows gradually from one revision per year to two revisions per year (on average) by the end of the program.

Figure 4(b) shows the other two components of a firm's pricing plan: firm-specific inflation rate ($\omega_t(z)$) and the 'initial' relative price ($p_t^{*N}(z)/P_t^N$) for a firm resetting prices at t . Note that the path of those variables for the case of constant nominal rigidities closely resembles the dynamics in Calvo et al. (2003). Firms resetting prices in the model's special case set lower initial relative prices (dashed line) but set higher growth rates for its initial price compared to firms with (elements of) state-dependent pricing. That is, the relative-price dispersion for firms resetting prices is larger when the

²²These 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.

²³In time-dependent models, the prediction that the recession phase starts immediately after the beginning of the program is also found in Calvo et al. (2003) or in Uribe (1999).

²⁴Coincidentally, this quantitative result is in line with firm-level evidence on the cost of pricing activities presented in Zbaraki et al. (2003). 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.

economy is subject to constant nominal rigidities.

Figure 4(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 ²⁵. The dynamics of those variables closely resemble the dynamics of Uribe's (1999) model with Calvo sticky prices.

[Figure 5 about here.]

Figure 5(a) 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, that is because the initial degree of nominal rigidities is similar in both economies. On the other hand, the equilibrium paths differ as prices become more flexible. SDNR allow for a faster recovery that brings the nontradable sector to levels above than its pre-disinflation level. The next section, shows that when the program is of uncertain duration, the recovery phase in the nontradable sector is weaker.

4.3. Program with Uncertain Duration

Following Mendoza and Uribe (1997) or Calvo and Drazen (1997), in an ERB (MB) program with uncertain duration, the monetary authority announces at time $t = 0$ a reduction in the depreciation rate (money growth rate) from $\varepsilon^h (= \rho^h) = 1.27$ to $\varepsilon^l (= \rho^l) = 1.024$. The public expects in date t the program to be abandoned in $t+1$ with probability $h_t \equiv \Pr(\varepsilon_{t+1} = \varepsilon^h | \varepsilon_t = \varepsilon^l)$ —similarly for MB programs I define $h_t \equiv \Pr(\rho_{t+1} = \rho^h | \rho_t = \rho^l)$. I also assume that the program ends with probability one in the period $t = \tau$, that is

²⁵The 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.

$h_{\tau-1} = 1$. Moreover, ε^h is an absorbent state in the sense that once ε^h is realized, the monetary authority keeps the high depreciation rate with probability one.

Based on the empirical evidence on devaluation probabilities by Blanco and Garber (1986), the hazard function assumed is J-shaped. The hazard function (in the upper right panel of Figures 6(a) and 6(b)) implies that when the disinflation is announced, the public expects the program to collapse in $t = 1$ with probability 0.4 ($h_0 = 0.4$); as the public builds confidence, the probability of collapse decreases to zero by the fourth quarter ($h_4 = 0$); then, confidence in the program starts to vanish so that the probability of abandonment rises gradually to one by the eleventh quarter ($h_{11} = 1$). The program lasts at most 12 quarters.

[Figure 6 about here.]

Figure 6 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 model's special case of constant nominal rigidities when the program lasts for 12 quarters. To isolate the effects of habit formation, I assume time separability in consumption ($\varphi = 0$); all other parameters values are in Table 1.

Figure 6(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 one of uncertain duration.

A key difference with respect to the previous experiment arises for MB disinflation programs. Figure 6(b) shows that when we account for uncertainty, both models predict that the initial contraction in nontradables keeps the level of consumption below its pre-disinflation level along the equilibrium path.

4.4. Sensitivity Analysis

I perform sensitivity analysis in four key parameter values. First, I allow for lower degree of nominal rigidities by setting $(1 - \alpha_H) = 0.7$ and $(1 - \alpha_L) = 0.3$; second, I extend the duration of the temporary program to 24 quarters; third, I simulate a higher elasticity of money demand with respect to $i/(1 + i)$; and fourth, I assume logarithmic utility in leisure. The simulations with the alternative calibrations confirm the discrepancies in the dynamics of nontradables (the sector with nominal rigidities) across economies with and without endogenous nominal rigidities for temporary ERB disinflations.²⁶

5. Concluding Remarks

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.

²⁶Impulse responses available upon request.

A. Appendix: 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 $\{a_t, \rho_t\}_{t=0}^{\infty}$. An *allocation* is a sequence of aggregate consumption, consumption of tradables, consumption of non-tradables, 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), (25a), (25b) and (25c). iii) The nontradable goods market clears $c_t^N(z) = y_{c,t}^N(z) \forall z$, and the labor market clears $n_t = \int_0^1 n_t(z) dz$ at a wage rate W_t .

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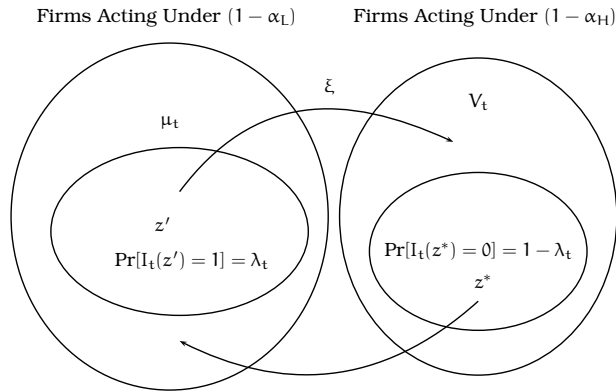


Figure 1: Pricing Mechanism

The continuum of firms is formed by two disjoint sets of firms: the set μ , with mass μ_t , contains firms subject to the Calvo probability $(1 - \alpha_L)$; the set V , with mass V_t , is formed by firms subject to the Calvo probability $(1 - \alpha_H)$. The firm $z' \in \mu$ setting an optimal pricing policy at t , increases its probability of pricing-plan revisions to $(1 - \alpha_H)$ by paying the random lump-sum cost ξ , this event happens with probability λ_t . The firm $z^* \in V$ setting an optimal pricing policy at t decides not to pay the random cost by setting pricing-policies subject to $(1 - \alpha_L)$, this event happens with probability $(1 - \lambda_t)$.

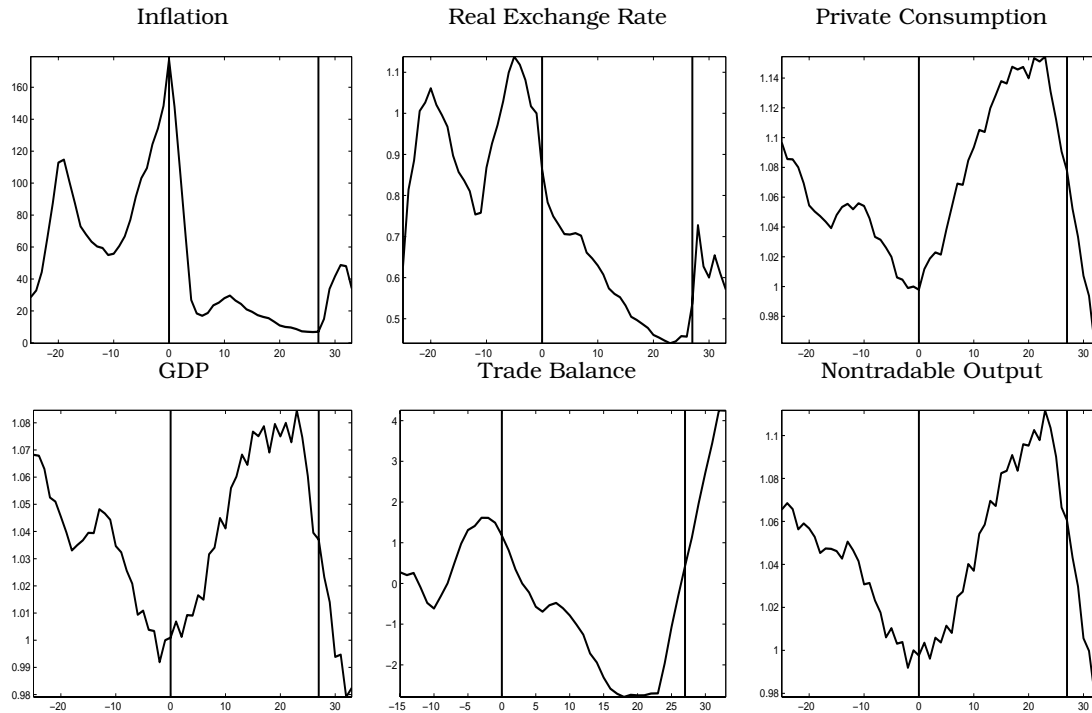


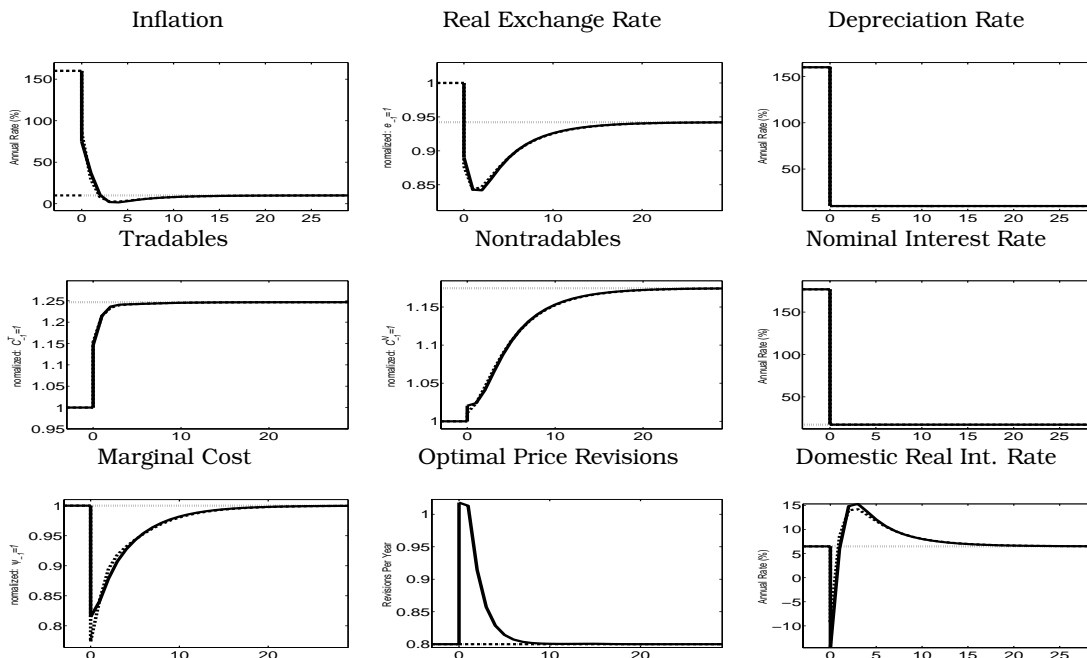
Figure 2: Mexico's 1987 ERB Disinflation

Note 1: All series are in real pesos of 1993 and normalized to one in the last quarter of 1987 ($t=-1$), except for inflation (per year) and trade balance (in billions of pesos), which are not normalized. Horizontal axis measures the number of quarters after 1988.1—when the program was put in place. The vertical lines indicate the beginning and end of the program.

Note 2: All series are seasonally adjusted and except for inflation and real exchange rate the series are detrended. Real exchange rate is defined as the CPI-adjusted nominal exchange rate between the Mexican peso and the US dollar (pesos per dollar). Nontradable output follows the sectoral classification in Mendoza and Uribe (1997).

Source: INEGI and Banco de México.

(a) PERMANENT ERB DISINFLATION PROGRAM



(b) PERMANENT MB DISINFLATION PROGRAM

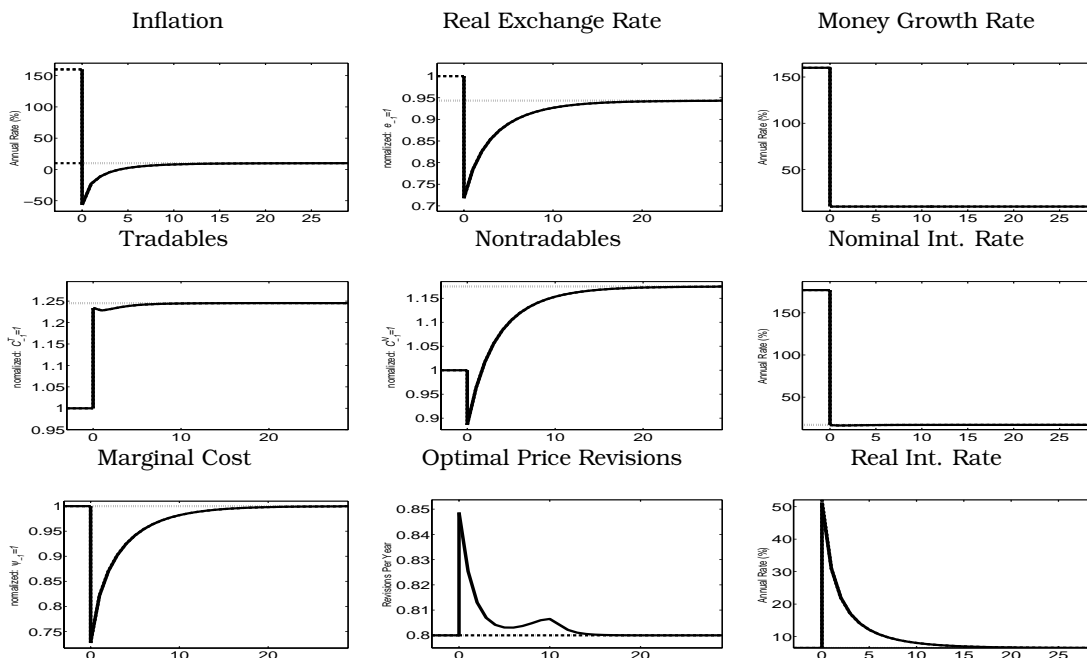


Figure 3: Permanent and Credible Disinflation Programs

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.

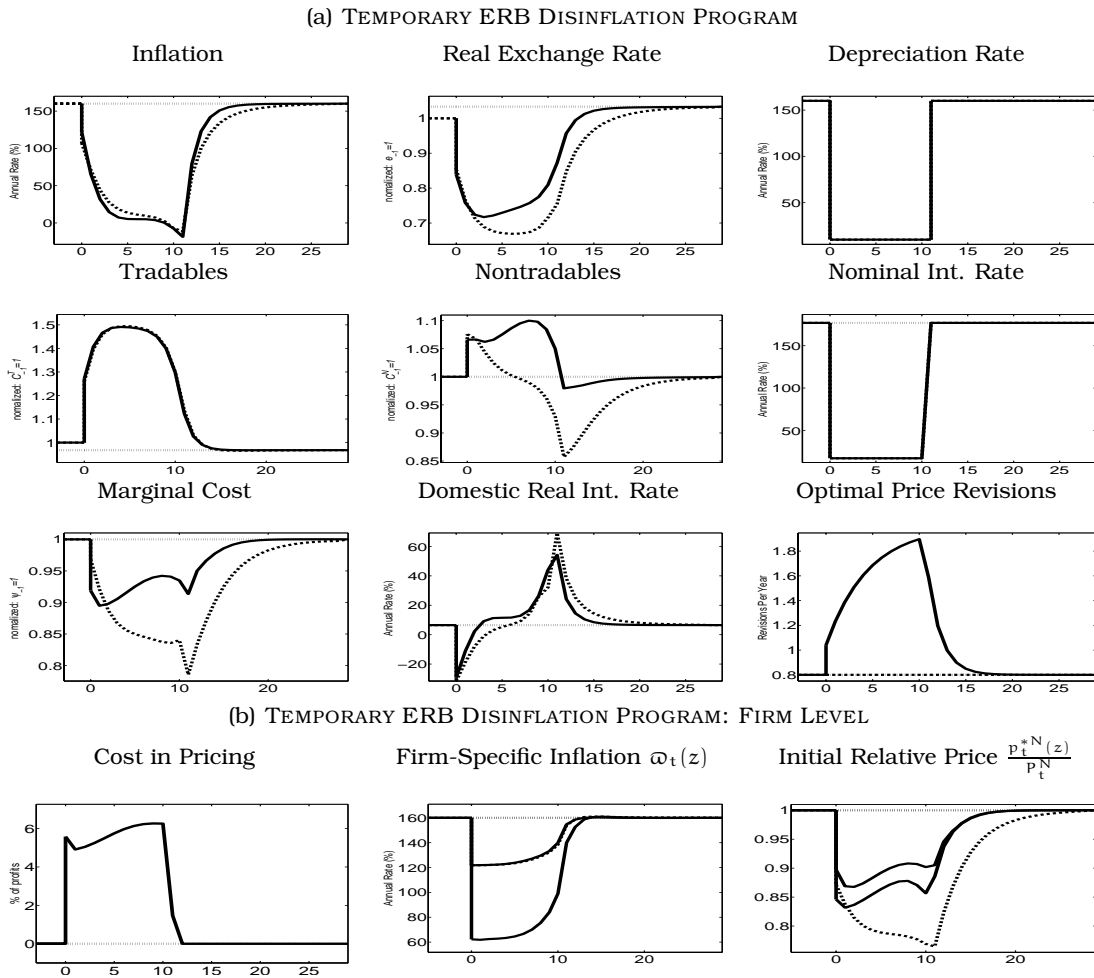
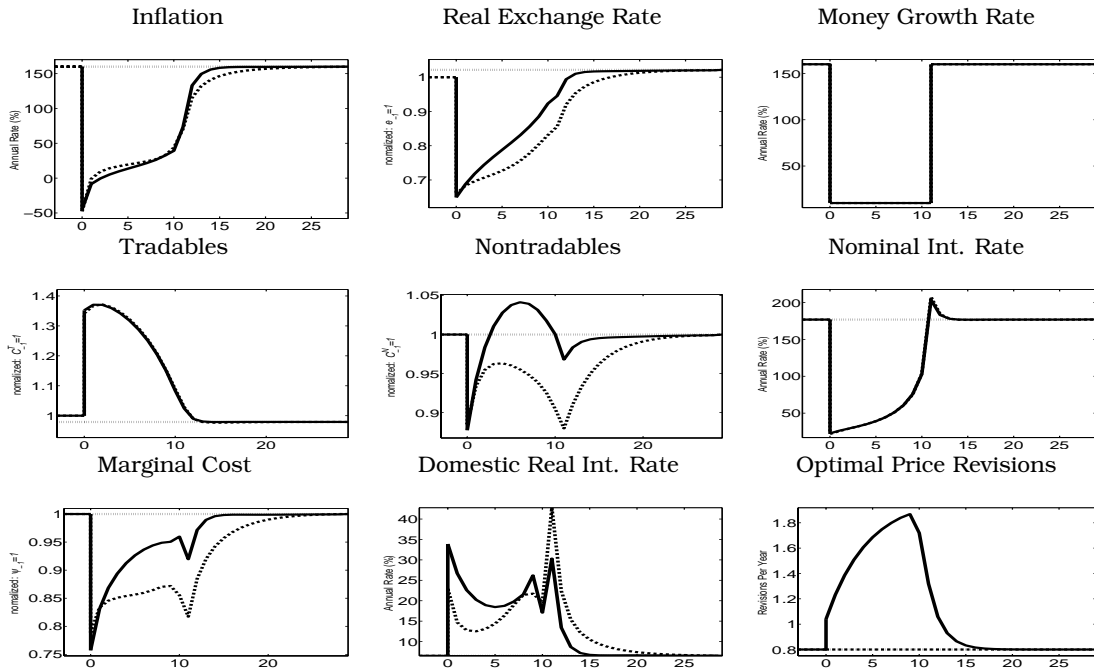


Figure 4: Temporary ERB Disinflation Program

The temporary ERB disinflation program consists in a reduction of the depreciation 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) TEMPORARY MB DISINFLATION PROGRAM



(b) TEMPORARY MB DISINFLATION PROGRAM: FIRM LEVEL

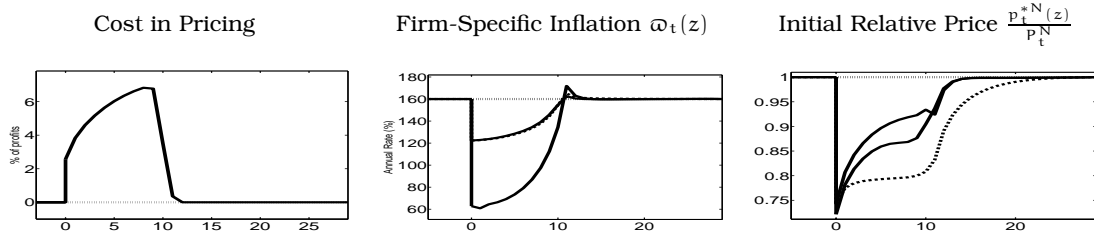
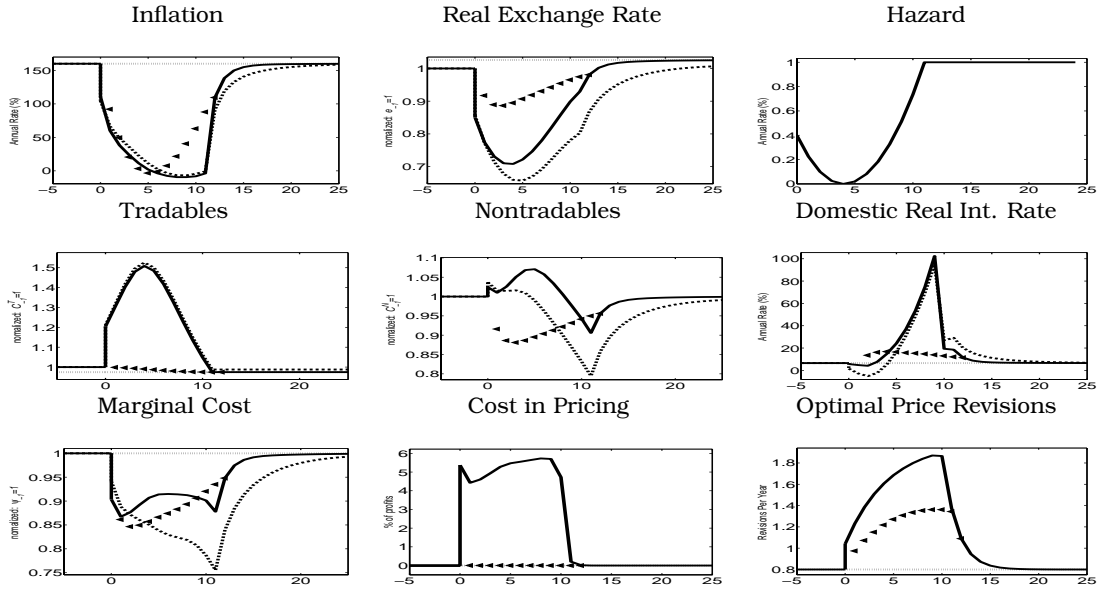


Figure 5: Temporary MB Disinflation Program

The temporary MB disinflation program consists in a reduction of the 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) ERB DISINFLATION WITH UNCERTAIN DURATION



(b) MB DISINFLATION WITH UNCERTAIN DURATION

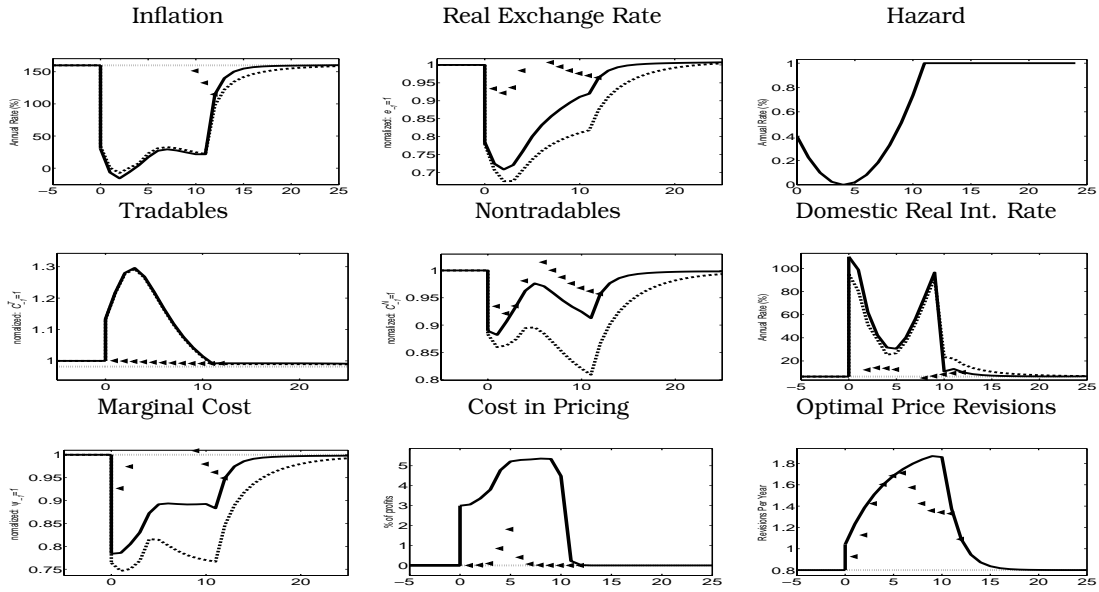


Figure 6: Disinflation Programs with Uncertain Duration

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.

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
Transaction Costs and Endowments	
$K = 3.8$	scale parameter in transaction costs technology
$\sigma = 1/0.2$	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)
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
Monetary Policy	
$\varepsilon^h (= \rho^h) = 1.27$	Quarterly gross devaluation (money growth) rate before the program
$\varepsilon^l (= \rho^l) = 1.024$	Quarterly gross devaluation (money growth) rate during the program
$\tau = 12$	Time duration of the program in quarters (temporary program)

Table 1: Baseline Calibration

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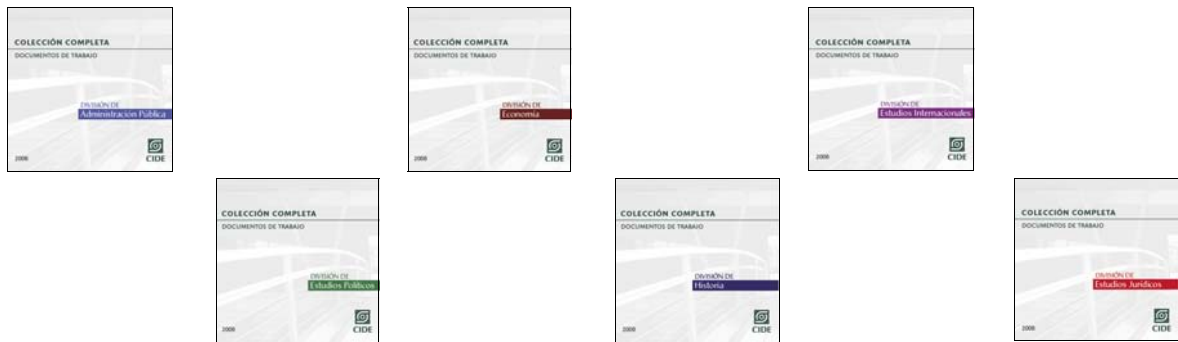
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