

ABSTRACT

Title of dissertation: ESSAYS ON EXCHANGE-RATE-BASED
 STABILIZATION UNDER FISCAL CONSTRAINTS

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Exchange-rate-based inflation stabilization programs cause a sizable loss of inflation tax revenue and thus open a fiscal gap. The stabilization literature usually assumes that this gap can be closed by raising lump-sum (nondistortionary) taxes and/or cutting lump-sum transfers. As such policies are difficult to implement in practice, these two essays analyze two alternatives.

The first essay explores the implications of raising a conventional income tax to make up for the loss of inflation tax revenue in the context of an exchange-rate-based stabilization program in an open economy with sticky prices and monopolistic competition. The combination of smaller monetary and larger tax distortion in the low-inflation steady state results in lower consumption and output of nontradable goods than in the high-inflation equilibrium. In addition, the recession accompanying the transition to the low-inflation steady state produces welfare losses. Nevertheless, the net welfare result is a gain, as larger money balances and more leisure time outweigh the cost of lower consumption. The essay also explores the sensitivity of this welfare trade-off to various structural characteristics of the economy and exogenous factors.

The second essay assumes that both tax and spending policies are inflexible and looks instead at the role of monetary policy in closing the emerging fiscal gap. It shows that in a closed economy a monetary expansion can lower the real interest rate. This benefits the budget both by generating a money demand boom, which expands the base of the inflation tax, and by lowering the budget's interest payments. These effects are, however, dependent on the credibility of the stabilization program, as the same-size monetary expansion fails to achieve fiscal sustainability when credibility is lacking.

ESSAYS ON EXCHANGE-RATE-BASED STABILIZATION UNDER FISCAL
CONSTRAINTS

by

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1. Introduction

The theory and practice of exchange-rate-based stabilization programs has been the subject of abundant literature explaining the reasons for the success or failure of such programs by features of their design and implementation.¹ The main distilled lesson is that credibility, generated by a consistent macroeconomic policy mix, is an indispensable condition for success. As fiscal restraint plays a crucial role in achieving that consistent policy mix, most authors assume that the government is able to maintain a sustainable fiscal position after the start of the stabilization program, a necessary condition for permanently lowering inflation. This assumption is operationalized by endowing the fiscal authority with either access to lump-sum (i.e., nondistortionary) taxes, or an ability to cut lump-sum transfers just enough to offset the loss of inflation tax revenue stemming from the lower inflation without burdening the economy with additional distortions.

Such policies are, however, difficult to implement in the real world. In a high-inflation economy, a significant fraction of the government's fiscal revenue comes from the inflation tax on money holdings. Any credible disinflation program will therefore have to address the emerging fiscal gap that it has created by lowering inflation tax revenue. This revenue loss is typically a few percentage points of GDP (see Table 1). In their drive to ensure public support for the stabilization program and the overall reform agenda that usually accompanies it, even rational and nonmyopic governments face considerable constraints in their ability to achieve spending cuts of that magnitude, and large scale lump-sum taxes are not widespread. On the other hand, however, a widening fiscal deficit, with the concomitant rising public debt and (very often) a growing external current account deficit is bound to erode the credibility of the stabilization program as well. So countries with inflexible fiscal

¹A partial list includes Calvo (1986 and 1987), Drazen and Helpman (1988 and 1990), Kiguel and Liviatan (1992a and 1992b), Velasco (1993), Calvo and Vegh (1993, 1994, and 1999), Rebelo and Vegh (1995), Roldos (1993, 1995), Uribe (1995), Agenor and Montiel (1996), Talvi (1996).

policy face a dilemma - how to reconcile the loss of inflation tax revenue with the need to ensure the credibility of their stabilization policies.

This collection of essays explores two ways of addressing this dilemma. Both essays assume that fiscal expenditure is untouchable and look for alternative ways to save the stabilization. In the first essay, the policymaker complements the exchange rate anchor with a higher distortionary tax to make up for the lost inflation tax revenue in a two-good open economy with sticky prices and monopolistically competitive producers. In implementing such a policy mix, the government faces a welfare trade-off: it alleviates the monetary distortion caused by high inflation, but aggravates the distortion caused by the higher income tax. The combination of lower monetary and higher tax distortion results in lower consumption (and output) of nontradable goods than in the initial high-inflation equilibrium. Moreover, the recession accompanying the transition between the high-inflation and the low-inflation steady state produces additional welfare losses. Nevertheless, welfare increases on net, as higher money balances and more leisure time outweigh the cost of lower consumption. The essay also explores the sensitivity of the welfare trade-off to various structural characteristics of the economy and exogenous factors, such as the interest elasticity of money demand, the wage elasticity of labor supply, the international interest rate, the size of the government, the speed of disinflation, and the degree of price stickiness.

The second essay assumes that both spending and tax policies are inflexible and looks instead at the role of monetary policy in closing the emerging fiscal gap. It shows that in an economy closed to capital flows a monetary expansion can lower the real interest rate. This benefits the budget in two ways: by generating a consumption and money demand boom, which expands the base of the inflation tax, and by lowering the budget's interest payments. These effects are, however, dependent on the credibility of the stabilization, as the same-size monetary expansion fails to achieve fiscal sustainability when credibility is lacking and consumers perceive the stabilization as temporary.

2. The Trade-Off Inflation—Taxation in Exchange-Rate-Based Stabilization Programs

2.1. Introduction

This paper analyzes the consequences of substituting distortionary taxation for inflation tax revenue in an exchange-rate-based stabilization program.² In a high-inflation economy, a significant fraction of the government's fiscal revenue comes from the inflation tax on money holdings. Any credible disinflation program will therefore have to address the emerging fiscal gap that it has created by lowering inflation tax revenue. The traditional stabilization literature assumes that either lump-sum taxes are available, or lump-sum fiscal transfers are cut just enough to maintain fiscal sustainability.³ However, in their drive to ensure public support for the stabilization program and the overall reform agenda that usually accompanies it, even rational and nonmyopic governments face considerable constraints in their ability to cut fiscal transfers, and large scale lump-sum taxes are not widespread. Therefore, monetary policy is dominated by fiscal policy in its inflation-reducing effort: given the fiscal stance, the economy needs high inflation to stay in equilibrium. To make the inflation cut sustainable, the government thus needs to raise conventional distortionary taxes as needed to offset the lost revenue.⁴ For example, Table 1 provides a list of successful exchange-rate-based stabilization programs in Central and Eastern Europe, where the drop in inflation to single digits was accompanied by an increase of conventional tax revenue in terms of GDP, on account of various income and consumption taxes.

²The term "distortionary tax" applies to any tax that affects economic agents' incentives to consume, save or produce. Examples are income, consumption, and payroll taxes. For the sake of concreteness, our model uses an income tax.

³See, e.g., Calvo and Vegh (1993 and 1994), Roldos (1993 and 1995) and the survey in Rebelo and Vegh (1995). An exception is Talvi (1996).

⁴See Calvo (1987) and Talvi (1996) for the implications of an exchange-rate-based stabilization without a fiscal adjustment.

Table 1: Exchange-Rate-Based Stabilization and Tax Revenue in Central and Eastern Europe

Country	Start of Exchange-Rate-Based Stabilization	Year When Inflation Dropped Below 10 percent	Drop in Inflation Tax Revenue (percent of GDP)	Tax Revenue Increase (percent of GDP)
			1/ 2/	2/
Bulgaria	1997	1998	-5.9	5.3
Croatia	1993	1994	-4.0	7.6
Estonia	1992	1998	-21.7	8.6
Latvia	1994	1997	-2.4	4.7
Lithuania	1994	1997	-3.8	4.6
Average			-7.6	6.1

Sources: IMF, *International Financial Statistics*; and author's calculations.

1/ Inflation tax is computed as $m*inf/(1+inf)$, where m is the monetary base as a ratio to GDP and inf is the annual average inflation.

2/ Differences are between the year when inflation dropped below 10 percent and the year preceding the start of the stabilization program, except for Estonia and Latvia, for which the base year is the year of the program launch.

What does a stabilization package combining an exchange rate anchor with higher taxation imply for the dynamics of the macroeconomy? The recession in production of nontradables, brought about by their sticky inflation, is exacerbated by the additional distortion of higher taxation. The low-inflation steady state involves lower consumption (and production) of nontradables than in the original high-inflation point of departure. Consumers, however, benefit from a lower tax on money and less time at work. The net welfare result is a gain, as larger money balances and more leisure time outweigh the cost of lower consumption. The government runs a transitional deficit, which is financed by its initial stock of net foreign assets.⁵

⁵For analytical tractability, we abstract from current account effects by exogenizing the supply of tradables. This way, in a fully credible stabilization, consumption of tradables does not deviate from its steady state.

In implementing such a policy mix, the government faces a welfare trade-off: it alleviates the monetary distortion caused by high inflation, but aggravates the distortion caused by the higher income tax, in addition to the cost of the recession during the transition between the steady states. Thus, there might be inflation/income tax combinations that would not be welfare improving compared with the original state. The paper investigates the sensitivity of the welfare gain to changes in the economy's structural parameters, specifically the interest elasticity of money demand, the wage elasticity of labor supply, the international interest rate, the size of the government, the speed of disinflation, and the degree of price stickiness.

The model employed is an extension of Calvo, Celasun, and Kumhof (2003). They enhance the standard exchange-rate-based stabilization setup by assuming that, in a staggered price setting, firms choose both a price level and a firm-specific inflation rate when they get their price-updating signal (which gives rise to "sticky inflation" in addition to sticky prices). This assumption allows them to generate inflation persistence in a forward-looking model fully derived from microfoundations.⁶ They show that, even in a fully credible exchange-rate-based stabilization, inflation does not converge immediately to the rate of change of the nominal anchor, owing mostly to the existing share of predetermined firm-specific inflation rates. The slow disinflation leads to sizable real exchange rate appreciation and a temporary recession. Thus, stabilization involves a welfare trade-off between the gain of permanently lower inflation and the cost of a transitional recession. In the present paper, this trade-off is exacerbated by the higher tax rate in the low-inflation steady state. To reveal the contribution of "sticky inflation" to the welfare results, this paper also recasts the production side of the model in terms of the traditional sticky prices and finds out that sticky inflation slightly lowers the welfare gain.

⁶Generating endogenous inflation persistence and short-run output loss upon disinflation in forward-looking dynamic general equilibrium models with nominal rigidities has proved tricky. See the surveys provided by Clarida, Gali, and Gertler (1999), Lane (2001), and Gali (2002).

A few recent papers have also considered the implications of distortionary taxation for monetary policy conduct in the context of sticky prices (Benigno and Woodford, 2003, Coreia, Nicolini, and Teles, 2002, Schmitt-Grohe and Uribe, 2004; and Siu, 2002). This study differs from them in three important aspects. First, these papers are concerned with the conduct of optimal monetary (and fiscal) policy in the presence of sticky prices, distortionary taxation, and a flexible exchange rate; in our paper, we analyze the combination of sticky prices/inflation and distortionary taxation in an exchange-rate-based stabilization program with an exogenously chosen exchange rate depreciation target, a feature consistently observed in reality. Second, this paper employs the assumption of Calvo, Celasun, and Kumhof (2003) that, in the context of sticky prices à la Calvo (1983), firms choose both a price level and a firm-specific inflation rate when they get the price-updating signal. This assumption is less restrictive and more intuitively and empirically plausible than the traditional sticky price approach, employed in the four papers listed above.⁷ Third, we develop a two-goods model, which allows the dynamics of the real exchange rate to be endogenized.

The paper is organized as follows. Section 2 introduces the basic model (the consumer and producer problems, and government policies and constraints), defines equilibrium and specifies the dynamic system that describes the economy's behavior. Section 3 calibrates and solves numerically the basic model, while Section 4 presents welfare analysis, including welfare sensitivity to parameter configuration, pricing, and policy assumptions. Section 5 rewrites the model in terms of the traditional sticky prices, in order to analyze the contribution of the assumption of a firm-specific inflation rate to the welfare results. Section 6 concludes.

⁷The firms choose only their price and update it thereafter at the steady state inflation rate. See Calvo (1983) and Yun (1996).

2.2. The Model

A small open economy consists of a representative consumer, a continuum, indexed by $j \in 0, 1$, of monopolistically competitive producers of nontradable goods, and a government. Both the consumer and the producers make their decisions in an infinite horizon, discounting the future with their respective discount factors. Prices of the tradable goods obey the purchasing power parity and normalizing the foreign price level to one makes the price index of tradables equal to the nominal exchange rate, E_t . The aggregate price level of nontradable goods is denoted by P_t , and the associated inflation rate by $\pi_t = \dot{P}_t/P_t$. The relative price of tradables in terms of nontradables (the real exchange rate) is $e_t = E_t/P_t$. Free capital mobility ensures that the uncovered interest parity holds:

$$i_t = r + \varepsilon_t, \quad (1)$$

where i_t is the nominal interest rate on domestic-currency-denominated assets, r is the exogenous, constant, and positive real international interest rate, and $\varepsilon_t = \dot{E}_t/E_t$ is the rate of exchange rate depreciation, assumed greater than $(-r)$ at all times, so that the nominal interest rate is always positive.

2.2.1. Consumers

The representative consumer maximizes lifetime utility by choosing her level of consumption of homogenous tradable goods, c_t^* , heterogeneous nontradable goods, $c_t(j)$, $j \in 0, 1$, nominal money balances, M_t and labor supply to producers, L_t . Conventionally, the rate at which consumers discount the future is assumed equal to the real return, r , on international bonds, b_t , measured in units of tradable goods. Consumption of nontradables is defined as a Dixit-Stiglitz aggregate over the continuum of differentiated goods j :

$$c_t = \left(\int_0^1 c_t(j)^{\frac{\sigma-1}{\sigma}} dj \right)^{\frac{\sigma}{\sigma-1}}, \quad (2)$$

with elasticity of substitution $\sigma > 1$. Let $P_t(j)$ be the price of the individual good $c_t(j)$. Then it can be shown through cost minimization of aggregate consumption spending that

$$c_t(j) = c_t \left(\frac{P_t(j)}{P_t} \right)^{-\sigma}, \quad (3)$$

where the aggregate price index of nontradables P_t is

$$P_t = \left(\int_0^1 P_t(j)^{1-\sigma} dj \right)^{\frac{1}{1-\sigma}}. \quad (4)$$

The representative consumer's objective function is

$$\text{Max} \int_0^\infty \left[\gamma \ln(c_t^*) + (1 - \gamma) \ln(c_t) + \theta \frac{m_t^{1-\frac{1}{\beta}}}{1-\frac{1}{\beta}} - \kappa \frac{L_t^{1+\frac{1}{\mu}}}{1+\frac{1}{\mu}} \right] e^{-rt} dt, \quad (5)$$

where $m_t = M_t/E_t$ are real money balances. The presence of money in the utility function is justified by the empirically observable sensitivity of money to the interest rate, which cannot be obtained under, for example, a cash-in-advance constraint. The separability of money from the other arguments of utility provides for analytical tractability and does not materially influence the results. The supply of tradable goods, y^* , is assumed constant and exogenous. The consumer also receives lump-sum transfers, g_t , in terms of tradables from the government and nominal wages, $W_t L_t$ (taxable at a proportional rate τ_t), as well as nominal lump-sum profit distributions, $\int_0^1 \Pi_t(j) dj$, from the producers. Her flow budget constraint is thus

$$\dot{b}_t = rb_t - \dot{m}_t - \varepsilon_t m_t + y^* - c_t^* + g_t + \frac{(1 - \tau_t)W_t L_t}{E_t} + \frac{\int_0^1 \Pi_t(j) dj}{E_t} - \frac{\int_0^1 P_t(j) c_t(j) dj}{E_t} . \quad (6)$$

After imposing the standard transversality condition, $\lim_{t \rightarrow \infty} (b_t + m_t) e^{-rt} \geq 0$, we can convert (6) into a lifetime budget constraint:

$$\begin{aligned} & b_0 + m_0 + \int_0^\infty \left[y^* + g_t + \frac{(1 - \tau_t)W_t L_t}{E_t} + \frac{\int_0^1 \Pi_t(j) dj}{E_t} \right] e^{-rt} dt \quad (7) \\ & \geq \int_0^\infty \left[c_t^* + \frac{\int_0^1 P_t(j) c_t(j) dj}{E_t} + i_t m_t \right] e^{-rt} dt . \end{aligned}$$

The consumer maximizes (5) subject to (7). The first-order conditions are (7) holding with equality, (3), and

$$\frac{\gamma}{c_t^*} = \lambda , \quad (8)$$

$$\frac{c_t}{c_t^*} = e_t \frac{1 - \gamma}{\gamma} , \quad (9)$$

$$m_t = \left(\frac{\gamma i_t}{\theta c_t^*} \right)^{-\beta} , \text{ and} \quad (10)$$

$$w_t \equiv \frac{W_t}{P_t} = \frac{\kappa c_t L_t^{\frac{1}{\mu}}}{(1 - \gamma)(1 - \tau_t)} . \quad (11)$$

These equations are straightforward. According to equation (8), the marginal utility of consumption of tradables is equal to the marginal utility of wealth (the constant multiplier, λ , of the lifetime budget constraint (7)). Equation (9) equates the marginal rate of substitution between tradables and nontradables to their relative price, the real exchange rate. Equation (10) is a standard money demand function. Equation (11) provides the labor supply function, expressed as an equation for the real wage demanded by the consumer,

which is equal to the marginal rate of substitution between consumption and labor, adjusted for the distortion coming from the labor income tax.

2.2.2. Producers

Producers in the nontradables sector use only labor as an input and, for simplicity, have linear production functions:

$$y_t(j) = Bl_t(j), \quad j \in 0, 1, \quad (12)$$

where B is a constant technology factor. They take the nominal wage as given in the labor market, but are monopolistically competitive in the goods market and distribute all nominal profits, $\Pi_t(j)$, to the consumer in a lump-sum fashion:

$$\Pi_t(j) = P_t(j)y_t(j) - W_t l_t(j), \quad j \in 0, 1. \quad (13)$$

As in Calvo (1983), producers get only random and exogenous opportunities to change their prices, which opportunities are drawn from an exponential distribution with probability density $\delta e^{-\delta t}$. The realizations of these opportunities are independent of their previous occurrences, and across firms. Income uncertainty for the representative consumer is thus eliminated by the law of large numbers, despite firm-specific revenue uncertainty. At any given moment, a fraction δ of producers update their prices, while the average duration of a price contract is $\frac{1}{\delta}$.

Producers maximize the present discounted value of the stream of real future profits each time they get the price change signal. Their discount rate is the interest rate in terms of nontradables, $r + \varepsilon_t - \pi_t$; in addition, they weigh future profits by the probability $e^{-\delta(s-t)}$ that today's price will still be in force at time s . Producers' real marginal cost equals the

real wage in terms of nontradables, $w_t = W_t/P_t$, as determined by equation (11). They also receive a proportional output subsidy, $sub = \frac{1}{\sigma-1}$, from the government.⁸ As in Calvo, Celasun and Kumhof (2001 and 2003), whenever firms receive a price change signal at time t , they choose both their current price, V_t^j , and a firm-specific inflation rate, v_t^j , at which their price will be updated in every future period until the next opportunity to maximize profits. We therefore have

$$P_s(j) = V_t^j e^{v_t^j(s-t)} \quad (14)$$

for every product j and all $s > t$ until the next price update.

Specifically, producers maximize

$$\text{Max}_{V_t^j, v_t^j} \int_t^\infty e^{-\int_t^s (\delta+r+\varepsilon_r-\pi_r)dr} \left[\frac{V_t^j e^{v_t^j(s-t)}}{P_s} y_s(j)(1+sub) - w_s l_s(j) \right] ds, \quad (15)$$

subject to the production function (12) and goods demand (3), which can, using (14), be expressed as

$$y_s(j) = c_s \left(\frac{V_t^j e^{v_t^j(s-t)}}{P_s} \right)^{-\sigma} \quad (16)$$

and substituted in (15). As the maximization problem is identical for all firms that receive a price-changing opportunity, the firm index, j , can be dropped. The first-order condition for V_t is

$$\int_t^\infty e^{-\int_t^s (\delta+r+\varepsilon_r-\pi_r)dr} c_s \left(\frac{V_t e^{v_t(s-t)}}{P_s} \right)^{-\sigma} \left[\frac{V_t e^{v_t(s-t)}}{P_s} - \frac{w_s}{B} \right] ds = 0.$$

Let $p_t \equiv V_t/P_t$ be the initial relative price of new price setters. Then, using the fact that, for $s > t$, $P_s = P_t e^{\int_t^s \pi_r dr}$, we can rewrite the last condition as

⁸This offsets the steady state price distortion that arises under monopolistic competition (see Woodford (2002)).

$$\int_t^\infty e^{-\int_t^s (\delta+r+\varepsilon_r-\pi_r)dr} c_s \left(p_t e^{-\int_t^s (\pi_r-v_t)dr} \right)^{-\sigma} \left[p_t e^{-\int_t^s (\pi_r-v_t)dr} - \frac{w_s}{B} \right] ds = 0 . \quad (17)$$

In the steady state, to which the economy finally converges, we must have $\bar{\pi} = \bar{v} = \varepsilon^l$ and $\bar{p} = 1$.⁹ From (17), the steady state real wage is thus $\bar{w} = B$. The first-order condition for v_t is

$$\int_t^\infty e^{-\int_t^s (\delta+r+\varepsilon_r-\pi_r)dr} c_s \left(p_t e^{-\int_t^s (\pi_r-v_t)dr} \right)^{-\sigma} (s-t) \left[p_t e^{-\int_t^s (\pi_r-v_t)dr} - \frac{w_s}{B} \right] ds = 0 . \quad (18)$$

Our strategy for deriving a dynamic system describing the behavior of the non-tradable sector of this economy is as follows. The evolution of all other variables in our economy can be expressed through four endogenous variables: the firm-specific inflation rate, v_t , the nontradables inflation rate, π_t , the weighted average of historic firm-specific inflation rates (call it ψ_t), and the producers' marginal cost, the wage rate w_t . Therefore, the dynamic behavior of the economy will be fully specified by a system describing the joint evolution of these four variables. To derive such a system, we use the definitions of the respective price indices and the producer and consumer first-order (optimal behavior) conditions, linearized around a stationary steady state.

First, we linearize (17) and (18) around the steady state and obtain the following expressions:¹⁰

$$\begin{aligned} p_t + \frac{v_t}{\delta+r} &= (\delta+r) \int_t^\infty e^{-(\delta+r)(s-t)} \left[\frac{w_s}{B} + \int_t^s \pi_r dr \right] ds , \text{ and} \\ \frac{p_t}{\delta+r} + \frac{2v_t}{(\delta+r)^2} &= (\delta+r) \int_t^\infty e^{-(\delta+r)(s-t)} (s-t) \left[\frac{w_s}{B} + \int_t^s \pi_r dr \right] ds = 0 \end{aligned} \quad (19)$$

⁹A bar above the respective variable denotes its steady state value.

¹⁰We use the following properties of the exponential distribution: $\delta \int_t^\infty (s-t) e^{-\delta(s-t)} ds = \frac{1}{\delta}$, $\delta \int_t^\infty (s-t)^2 e^{-\delta(s-t)} ds = \frac{2}{\delta^2}$.

Their derivatives with respect to time are

$$\dot{p}_t + \frac{\dot{v}_t}{\delta + r} = (\delta + r)\left(p_t - \frac{w_t}{B}\right) + v_t - \pi_t, \text{ and} \quad (20)$$

$$\dot{p}_t + \frac{2\dot{v}_t}{\delta + r} = v_t - \pi_t. \quad (21)$$

Combining (20) and (21) yields the following differential equation for the firm-specific inflation rate, v_t :

$$\dot{v}_t = -(\delta + r)^2 \left(p_t - \frac{w_t}{B}\right). \quad (22)$$

This is our first dynamic equation. Note that v_t is a jump variable, as upon receiving a price-changing signal it will be optimal for producers to allow discrete changes in both their current price and their firm-specific inflation rate.

Next we turn to the dynamics of the aggregate price index (4), which can be rewritten as

$$P_t = \left(\delta \int_{-\infty}^t e^{-\delta(t-s)} (V_s e^{v_s(t-s)})^{1-\sigma} ds \right)^{\frac{1}{1-\sigma}}, \quad (23)$$

where $\delta e^{-\delta(t-s)}$ is the weight of the price V_s and the firm-specific inflation rate v_s . Taking the derivative of (23) with respect to time, we obtain

$$\pi_t = \frac{\delta}{1-\sigma} (p_t^{1-\sigma} - 1) + \delta \int_{-\infty}^t e^{-\delta(t-s)} \left(p_s e^{-\int_s^t (\pi_r - v_s) dr} \right)^{1-\sigma} v_s ds. \quad (24)$$

Linearizing this expression around the steady state yields

$$(\pi_t - \bar{\pi}) = \delta(p_t - 1) + \delta \int_{-\infty}^t e^{-\delta(t-s)} \left[(v_s - \bar{v}) + \bar{v}(1-\sigma)(p_s - 1) - \int_s^t (\pi_r - v_s) dr \right] ds. \quad (25)$$

This expression can be simplified by linearizing the price index (23) around the steady state:

$$\delta \int_{-\infty}^t e^{-\delta(t-s)}(1-\sigma) \left[(p_s - 1) - \int_s^t (\pi_r - v_s) dr \right] ds = 0, \quad (26)$$

with the last equality following from the linearization of the first-order condition (17) around the steady state. Substituting (26) into (25), we obtain

$$(\pi_t - \bar{\varepsilon}) = \delta(p_t - 1) + \delta \int_{-\infty}^t e^{-\delta(t-s)}(v_s - \bar{\varepsilon}) ds. \quad (27)$$

The weighted average of firm-specific inflation rates currently in force, ψ_t , is defined as

$$\psi_t = \delta \int_{-\infty}^t e^{-\delta(t-s)} v_s ds. \quad (28)$$

Its time derivative is

$$\dot{\psi}_t = \delta(v_t - \bar{\varepsilon}) - \delta(\psi_t - \bar{\varepsilon}). \quad (29)$$

Using (28), we can rewrite the expression for aggregate inflation (27) as

$$(\pi_t - \bar{\varepsilon}) = (\psi_t - \bar{\varepsilon}) + \delta(p_t - 1). \quad (30)$$

The first term reflects inertia in the aggregate inflation rate through the historic pricing policies of firms that have not yet received a price-changing opportunity. The second term, the initial relative price of new price setters, p_t , is free to jump at the start of the stabilization program ($t=0$). Therefore, despite the presence of a predetermined component, aggregate inflation is a "jump" variable. Using (21), (22), (29), and (30), its derivative with respect to time equals

$$\dot{\pi}_t = -(3\delta + 2r)(\psi_t - \bar{\varepsilon}) + 2\delta(v_t - \bar{\varepsilon}) + (\delta + 2r)(\pi_t - \bar{\varepsilon}) - \frac{2\delta(\delta + r)}{B} (w_t - B). \quad (31)$$

Expression (30) can also be used to rewrite the differential equation for firm-specific inflation (22) as

$$\dot{v}_t = \frac{(\delta + r)^2}{\delta}(\psi_t - \bar{\varepsilon}) - \frac{(\delta + r)^2}{\delta}(\pi_t - \bar{\varepsilon}) + \frac{(\delta + r)^2}{B}(w_t - B) . \quad (32)$$

In order to link the dynamics of the consumer and producer part of this economy, the system of differential equations (29), (31), and (32) must be completed with an equation for the evolution of real marginal cost, w_t , derived from (11). As we will use relations that hold in equilibrium, we must first describe government policies and define equilibrium.

2.2.3. Government Policies and Constraints

The government owns a stock of net foreign assets, h_t , issues money, M_t , collects labor income tax, $\tau_t W_t L_t$, and makes lump-sum transfers, g_t , as well as subsidy payments, $\frac{1}{\sigma-1}$, per unit of output of nontradable goods. Its flow budget constraint in terms of tradables is

$$\dot{h}_t = r h_t + \dot{m}_t + \varepsilon_t m_t + \tau_t \frac{W_t L_t}{E_t} - g_t - \frac{1}{\sigma - 1} \frac{c_t}{e_t} , \quad (33)$$

where we have used the identity $\int_0^1 \left(\frac{P_t(j) y_t(j)}{E_t} \right) dj = \frac{c_t}{e_t}$. By imposing the transversality condition, $\lim_{t \rightarrow \infty} (h_t - m_t) e^{-rt} = 0$, we can transform (33) into the government's lifetime budget constraint

$$h_0 - m_0 + \int_0^\infty \left[\dot{m}_t + \tau_t \frac{W_t L_t}{E_t} - g_t - \frac{1}{\sigma - 1} \frac{c_t}{e_t} \right] e^{-rt} dt = 0 . \quad (34)$$

Government policies $\{\varepsilon_t, \tau_t, g_t\}_{t=0}^\infty$ must be such that, given the time paths $\{m_t, c_t, P_t, W_t\}_{t=0}^\infty$, the government budget constraint (34) holds. As discussed, fiscal expenditure is assumed to be inflexible, so real transfers, $\{g_t\}_{t=0}^\infty$, are constant over time. Exchange rate policy, $\{\varepsilon_t\}_{t=0}^\infty$, is the principal disinflation instrument, as the government

makes an unexpected announcement at time 0 of a lower rate of exchange rate depreciation:

$$\begin{aligned}\varepsilon_t &= \varepsilon^h, t \in (-\infty, 0), \\ \varepsilon_t &= \varepsilon^l, t \in 0, \infty).\end{aligned}\tag{35}$$

At the same time, the tax rate, τ_t , is raised from the existing rate τ^l to a new constant rate τ^h such that in the new steady state the higher income tax revenue offsets the lower inflation tax revenue in such a way that government net assets, h_t , are not explosive.¹¹ In other words, the government flow budget constraint, $\dot{h} = 0$, holds at the low-inflation steady state and thereafter. As the government faces no liquidity constraints, the steady state level of its reserves, \bar{h} , is simply determined by the transitional dynamics of (33), given h_0 .

2.2.4. Equilibrium

Let $f_t = b_t + h_t$ be the economy's overall level of net foreign assets. A perfect foresight equilibrium, given f_0 , the technology factor B , and an endowment of tradables, y^* , is a set of time paths $\left\{ \begin{array}{l} b_t, h_t, m_t, c_t^*, L_t, c_t, y_t, l_t(j), c_t(j), y_t(j), P_t, \\ W_t, P_t(j), V_t^j, v_t^j, E_t, \tau_t, g_t, j \in [0, 1] \end{array} \right\}_{t=0}^{\infty}$ such that:

(a) given f_0, B, y^* , government policies $\{\varepsilon_t, \tau_t, g_t\}_{t=0}^{\infty}$, and the price system $\{P_t, W_t, P_t(j), V_t^j, v_t^j\}_{t=0}^{\infty}$, the time paths $\{b_t, m_t, c_t^*, y_t, L_t, c_t, c_t(j)\}_{t=0}^{\infty}$ solve the consumer's problem of maximizing (5) subject to (7);

(b) given f_0, B, y^* , government policies $\{\varepsilon_t, \tau_t, g_t\}_{t=0}^{\infty}$, and the time paths $\{P_t, W_t, c_t\}_{t=0}^{\infty}$, the time sequences $\{V_t^j, v_t^j, y_t(j), l_t(j)\}_{t=0}^{\infty}$ solve the producers' problem of maximizing (15) subject to (12) and (16);

¹¹We assume that both τ^l and τ^h are below the revenue-maximizing tax rate so that revenue increases when the tax rate is raised.

(c) the nontradable goods market clears for all goods and at all times,

$$y_t(j) = c_t(j) \quad \forall t, \forall j \in [0, 1]; \text{ and} \quad (36)$$

(d) the labor market clears at all times,

$$L_t = \int_0^1 l_t(j) dj \quad \forall t. \quad (37)$$

Combining equations (34) and (7) holding with equality, and using the properties of equilibrium, we derive the following aggregate budget constraint:

$$f_0 + \frac{y^*}{r} = \int_0^\infty c_t^* e^{-rt} dt. \quad (38)$$

From (8), consumption of tradables is always constant. We therefore have

$$c_t^* = y^* + rf_0 \quad \forall t. \quad (39)$$

From (9), one can see that $\frac{c_t}{e_t}$ should also be constant throughout:

$$\frac{c_t}{e_t} = (y^* + rf_0) \frac{1 - \gamma}{\gamma} \quad \forall t. \quad (40)$$

Applying the condition $\dot{h} = 0$ to the government budget constraint (33), and using (9) and the equilibrium condition $\bar{w} = B$, one can express τ^h as

$$\tau^h = \frac{\gamma}{1 - \gamma} \frac{(g - r\bar{h}^l)}{(y^* + rf_0)} + \frac{1}{\sigma - 1} - \frac{\theta^\beta}{1 - \gamma} \left(\frac{\gamma}{\theta y^*} \right)^{1-\beta} \frac{\varepsilon^l}{(r + \varepsilon^l)^\beta}, \quad (41)$$

where \bar{h}^l is the amount of government assets in the low-inflation steady state.¹² This ex-

¹²This derivation also uses the relation $\bar{L} = \frac{\bar{c}}{B}$. See the next section.

pression can be simplified further by assuming, without loss of generality, that the initial level of the economy's net foreign assets is $f_0 = 0$ and also noting that g is implied from the initial high-inflation equilibrium as

$$g = rh_0 + \left[\tau^l - \frac{1}{\sigma - 1} \right] \frac{1 - \gamma}{\gamma} y^* + \varepsilon^h \left(\frac{\gamma(r + \varepsilon^h)}{\theta y^*} \right)^{-\beta}, \quad (42)$$

and therefore

$$\tau^h = \tau^l + \frac{\gamma}{1 - \gamma} \frac{r(h_0 - \bar{h})}{y^*} + \frac{\theta^\beta}{1 - \gamma} \left(\frac{\gamma}{\theta y^*} \right)^{1 - \beta} \left[\frac{\varepsilon^h}{(r + \varepsilon^h)^\beta} - \frac{\varepsilon^l}{(r + \varepsilon^l)^\beta} \right]. \quad (43)$$

The tax rate necessary to maintain fiscal sustainability is increasing in the initial size of the government, τ^l , in the loss of interest income during the transition between the steady states, and in the targeted cut in inflation (in a nonlinear way). It is decreasing in the elasticity of money demand.¹³ This equation demonstrates the trade-off the policymaker is facing: a more ambitious inflation target leads, *ceteris paribus*, to a larger tax distortion for a given level of revenue.

As noted in the analysis of the producers' behavior above, $\bar{\pi} = \bar{v} = \varepsilon^l$, $\bar{p} = 1$, and $\bar{w} = B$. Using the latter in the consumer first-order condition (11), plus the relation $\bar{L} = \frac{\bar{c}}{B}$, one arrives at

$$\bar{c}^h = B \left(\frac{(1 - \gamma)(1 - \tau^l)}{\kappa} \right)^{\frac{\mu}{1 + \mu}}; \quad \bar{c}^l = B \left(\frac{(1 - \gamma)(1 - \tau^h)}{\kappa} \right)^{\frac{\mu}{1 + \mu}}, \quad (44)$$

where \bar{c}^h and \bar{c}^l are the steady state levels of consumption of nontradables in the high- and

¹³For inelastic money demand, ($\beta < 1$), inflation tax revenue declines with inflation and the last term in (43) is positive. For a sufficiently large β , however, money demand grows more than proportionately with the cut in inflation, so that inflation tax revenue in fact increases. As this case involves no trade-off – the government can cut both inflation and taxes – we have ruled it out.

low-inflation states, respectively. It follows that

$$\frac{\bar{c}^l}{\bar{c}^h} = \left(\frac{1 - \tau^h}{1 - \tau^l} \right)^{\frac{\mu}{1+\mu}} < 1, \quad (45)$$

the steady state consumption of nontradables \bar{c} is unambiguously lower in the low-inflation steady state. The impact on consumer's welfare is, however, ambiguous in principle, as lower consumption goes hand in hand with less labor effort. We will come back to this issue in Section 4.

2.2.5. Dynamic System

To derive a differential equation for real marginal cost, w , we linearize equation (11) around the steady state, obtaining¹⁴

$$(w_t - B) = (\ln c_t - \ln \bar{c}) + \frac{1}{\mu}(\ln L_t - \ln \bar{L}) + \frac{1}{1 - \bar{\tau}}(\tau_t - \bar{\tau}). \quad (46)$$

Following the steps in Appendix A in Calvo, Celasun, and Kumhof (2003), one can show that $\bar{L} = \frac{\bar{c}}{B}$ and that, around the steady state,

$$\ln L_t - \ln \bar{L} = \ln c_t - \ln \bar{c}. \quad (47)$$

Therefore (46) becomes

$$(w_t - B) = \left(1 + \frac{1}{\mu}\right)(\ln c_t - \ln \bar{c}) + \frac{1}{1 - \bar{\tau}}(\tau_t - \bar{\tau}). \quad (48)$$

From the linearization of equation (9), the first term of equation (48) is

¹⁴It is more convenient to log linearize the right-hand side with respect to c_t and L_t .

$$(\ln(c_t) - \ln(\bar{c})) = (\ln(c_t^*) - \ln(\bar{c}^*)) + (\ln(e_t) - \ln(\bar{e})) . \quad (49)$$

Substituting (49) in (48) and differentiating the result over time while using the fact that $\dot{c}_t^* = \dot{e}_t = \dot{\tau}_t = 0$ (at points where they do not jump), as well as

$$(\ln e_t)^\bullet = \varepsilon_t - \pi_t , \quad (50)$$

we finally obtain

$$\dot{w}_t = -B\left(1 + \frac{1}{\mu}\right)(\pi_t - \bar{\varepsilon}) + B\left(1 + \frac{1}{\mu}\right)(\varepsilon_t - \bar{\varepsilon}) . \quad (51)$$

This equation says that a real appreciation is associated with a fall in real wages in the nontradables sector. The reason is that the higher relative price of nontradables lowers the demand for these goods and, therefore, for labor, depressing the real wage.

We now show that, while w_t can jump, it is not a free-jumping variable and can in this sense be considered predetermined. Consider equation (48), with (49) substituted in and the possibility of jumps at time 0. The real exchange rate is predetermined under a predetermined nominal exchange rate and sticky prices, while the tradables consumption path is a function only of the exogenous endowment, y^* . Jumps in ε_t and τ_t are also exogenous. Therefore w_t is a predetermined variable, in the sense that in the four-dimensional space defined by the variables ψ , v , π , and w , it can only jump to specific points exogenously determined by government policies and exogenous variables. The same goes for the weighted average of existing firm-specific inflation rates, ψ_t . The variables v_t and π_t are free to jump at time 0 to any point in the four-dimensional space of the system. The full dynamic system for this economy is represented by equations (29), (31), (32), and (51). In matrix form it looks as follows:

$$\begin{bmatrix} \dot{\psi}_t \\ \dot{v}_t \\ \dot{\pi}_t \\ \dot{w}_t \end{bmatrix} = \begin{bmatrix} -\delta & \delta & 0 & 0 \\ \frac{(\delta+r)^2}{\delta} & 0 & -\frac{(\delta+r)^2}{\delta} & \frac{(\delta+r)^2}{B} \\ -(3\delta+2r) & 2\delta & (\delta+2r) & \frac{-2\delta(\delta+r)}{B} \\ 0 & 0 & -Q & 0 \end{bmatrix} \begin{bmatrix} (\psi_t - \bar{\varepsilon}) \\ (v_t - \bar{\varepsilon}) \\ (\pi_t - \bar{\varepsilon}) \\ (w_t - B) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ Q \end{bmatrix} (\varepsilon_t - \bar{\varepsilon}). \quad (52)$$

where $Q = B(1 + \frac{1}{\mu})$.

This system has two eigenvalues with positive real parts and two with negative real parts.¹⁵ Given the number of predetermined variables, this proves that the system is saddle-path stable. For a broad range of relevant parameter values, all roots are real and associated with linearly independent eigenvectors, a sufficient condition for a unique saddle-path solution.¹⁶

The path of the government's net foreign assets on the economy's way to the new steady state is given by (33). Our government can borrow freely at the constant international interest rate, r , so there is no terminal condition for the steady state value of government assets \bar{h} . Given the initial value h_0 (equal to the high-inflation steady state value of h) and (33), \bar{h} is completely determined.

2.3. Model Solution

2.3.1. Calibration

The model can only be solved numerically. The chosen parameter values are shown in Table 2. The time unit is one quarter.

¹⁵The determinant and the trace of the coefficient matrix are positive, establishing that there are either zero or two eigenvalues with negative real parts. On the other hand, the sum of the four 3x3 principal minors is negative, which implies that exactly two roots have negative real parts.

¹⁶We searched over the range $\delta \in 0.05, 1$, corresponding to a price contract length between 1 and 20 quarters, and a real interest rate r between 4 percent and 16 percent per annum.

Table 2: Parameter Values

Name	Value	Description
σ	13/3	Intratemporal elasticity of substitution between nontradable goods
ε^h	0.20	Initial exchange rate depreciation (per annum)
ε^l	0.10	Final exchange rate depreciation (per annum)
τ^l	0.246	Tax rate in the high-inflation steady state (per annum)
r	0.05	Real interest rate in terms of tradables (per annum)
γ	0.5	Share of tradables in consumption
β	0.7	Interest elasticity of money demand
θ	0.013	Weight of money in the utility function
κ	5.558	Weight of labor in the utility function
μ	0.8	Wage elasticity of labor supply
L	1/3	Proportion of time spent working in the high-inflation steady state
\bar{y}^*	1/3	Output of tradables
δ	1/4	Inverse of average contract length in quarters (four)
f_0	0	Initial value of the economy's net foreign assets
B	1	Technology parameter in the production function

We calibrate θ , the weight of money in the utility function, so that money balances in the high-inflation steady state equal 0.25, the average ratio of cash in circulation to quarterly GDP in the five emerging markets in Central and Eastern Europe listed in Table 1. Similarly, κ , the weight of labor in the utility function, is calibrated from the high-inflation steady state. An interest rate elasticity of money demand of 0.7 allows for real money balances to expand by about 10 percent of GDP in the low-inflation steady state relative to the high-inflation one, which is again within the range observed in Central and Eastern Europe. We chose 0.8 for the labor supply elasticity, μ , balancing the need to maintain the empirically observed less-than-unitary elasticity in emerging markets, on the one hand, and, as low μ makes the transitional recession shallow and disinflation less costly, the desire not to bias the results in favor of disinflation, on the other. The currently low global interest rates motivate us to set the real interest rate in terms of tradables to 5 percent. Finally, we set the tax rate in the low-inflation steady state (τ^l) to 0.246, which is the average

prestabilization ratio of tax revenue to GDP in the countries in Table 1. For comparability of results, we take the rest of the parameters from Calvo, Celasun, and Kumhof (2003), and set the technology factor B to 1.

The numerical procedure of determining τ^h deserves some elaboration. First, we solve the government's flow budget constraint (33) for h_t as a function of the model's exogenous and endogenous variables. Then τ^h is set such that the amount of government assets, h_t in the very long run (1,000 periods after the start of the stabilization program) is the same as at 900 periods after the start (within a tolerance of 10^{-2}). This value of τ^h satisfies the condition $\dot{h} = 0$ in the presumed steady state (50 periods after the start) within a tolerance of at least 10^{-6} .

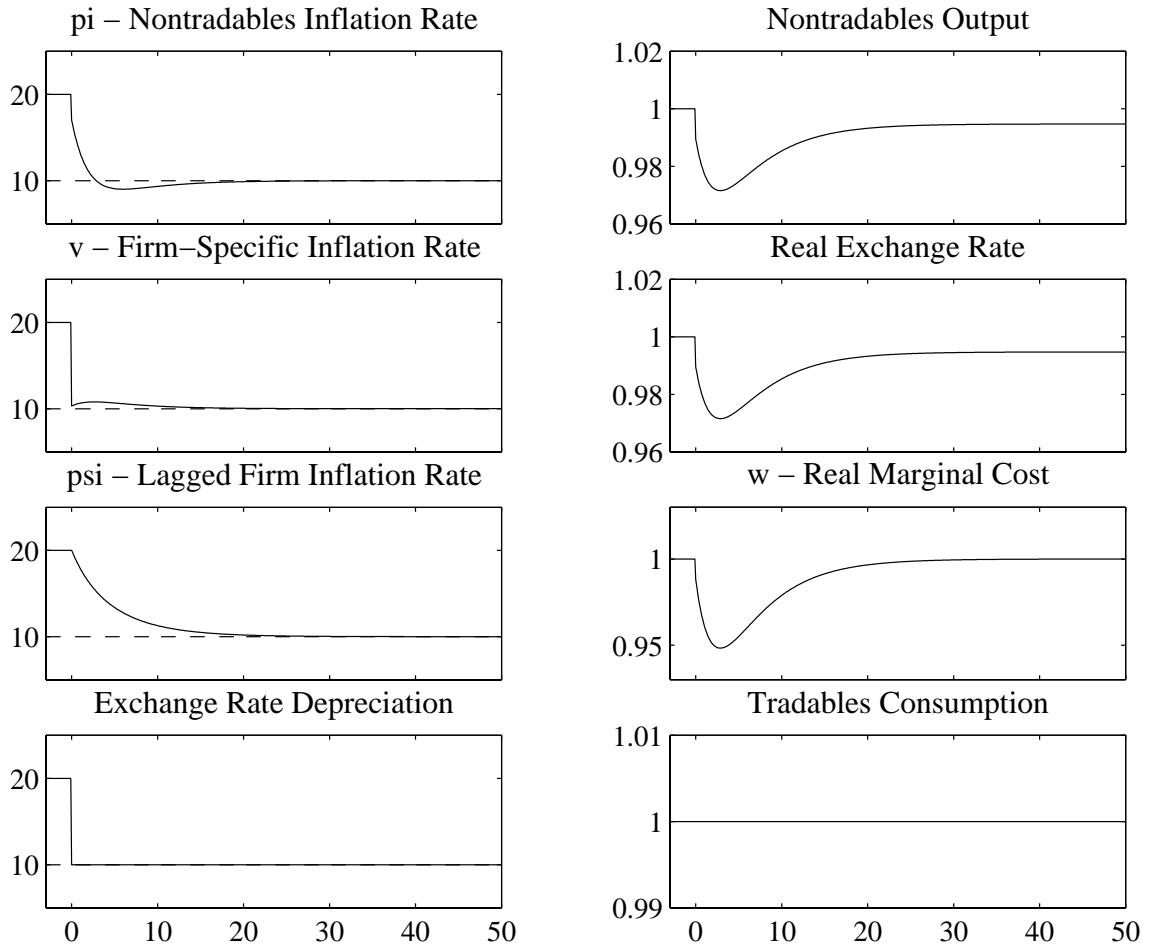
2.3.2. Dynamic Response of the Economy to Stabilization Policies

The dynamic transition paths of the main variables between the high- and low-inflation steady states are shown in Figure 1.¹⁷ Inflation of nontradables responds slowly to the permanently lower depreciation rate for two reasons (see equation (30)). First, the weighted average of firm-specific inflation rates, ψ , can only decline only because no more than a fraction δ of producers can update their pricing policies at any point in time. Second, given the undisputed permanency of disinflation, producers choose to put most of the weight of the price-updating response on the firm-specific inflation rate, v_t , rather than on the level of firm prices, p_t ; consequently, p_t is sluggish as well.

The slow response of nontradables inflation, combined with the immediately lower exchange rate depreciation, implies that the real exchange rate appreciates sharply, that is, nontradables become more expensive relative to tradables. This leads to a sharp but relatively short-lived recession, with a trough of about 3 percent and a duration of three-four

¹⁷Consumption/output series of tradables and nontradables are normalized to one for better visualization of their percentage changes.

Figure 1: Dynamic Paths of the Main Macroeconomic Indicators in the Baseline Case (in percent)



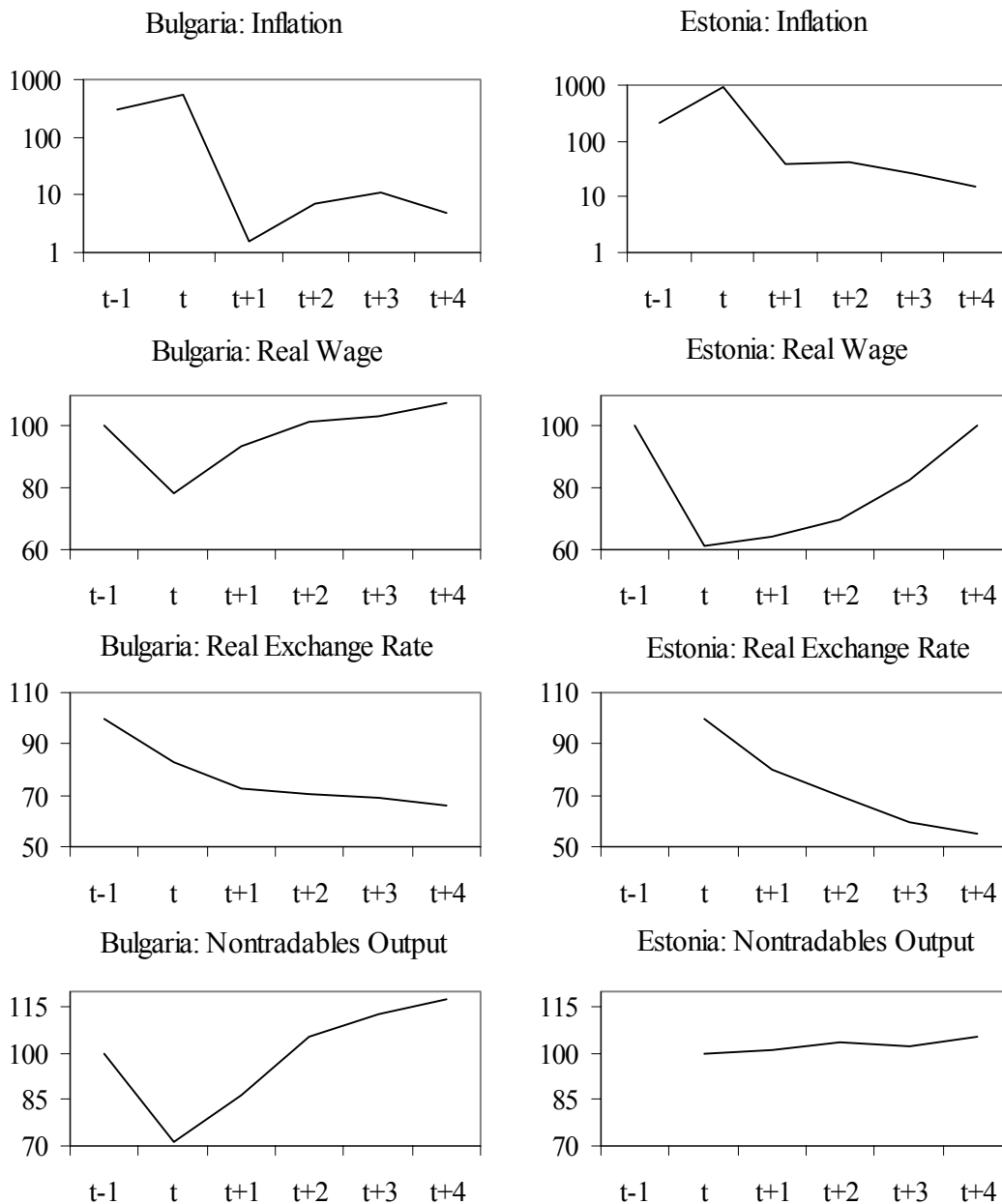
quarters. At the nadir, nontradables inflation starts undershooting the speed of exchange rate depreciation, and the real exchange rate starts depreciating toward its new steady state level, thereby ending the recession. Still, output rises very gradually and it takes over four years before the new steady state is reached (which is about 0.5 percent lower than the initial one under this parameter configuration). The presence of the higher tax rate (which settles at 29.04 percent) exacerbates and prolongs the recession and dampens the low-inflation steady state output of nontradables, compared to Calvo, Celasun, and Kumhof (2003). In

that paper, the trough in output loss is less than 2 percent below the high-inflation steady state; the recession has about the same duration, but the recovery is more vigorous, and the output of nontradables reaches its previous steady state level after five-six quarters and exceeds it by 1.7 percent in the new steady state. The loss of government assets in our model during the transition to the new steady state is about 1.7 percent of GDP.

How can we reconcile the model's predictions with the output booms usually associated with exchange-rate-based stabilization programs (as documented in, e.g., Kiguel and Liviatan, 1992a and 1992b, and Calvo and Vegh, 1999)? First, these output booms are predominantly in the tradables sector; output of nontradables often fell relative to tradables, which is consistent with our model. We chose to model explicitly the production of nontradables because these goods are subject to the distortion of sticky prices. Prices of tradables in a small open economy with an exchange rate anchor simply follow international prices and the exchange rate and are thus determined by exogenous and policy developments. Second, while we draw our illustration from emerging markets, we have outlined a general disinflation model, applicable to mature markets as well. In developed countries, disinflation has been more often associated with recessions than with booms (see, e.g., Christiano, Eichenbaum and Evans (1996 and 1998)).

Figures 2 and 3 show the evolution of selected macroeconomic indicators, corresponding to the main variables of our model, in four successful exchange-rate-based stabilization programs in Central and Eastern Europe. While these programs accompanied deep structural transformations in these economies during their transition from central planning to market — transformations that may have introduced additional (and different) macroeconomic dynamics — the main indicators do exhibit many of the features predicted by our model. The relatively slow disinflation gave rise to appreciating real exchange rates, the output of nontradables followed a V-shape or an U-shape relative to that of tradables, and in two of the cases the real wage dropped on impact before recovering later.

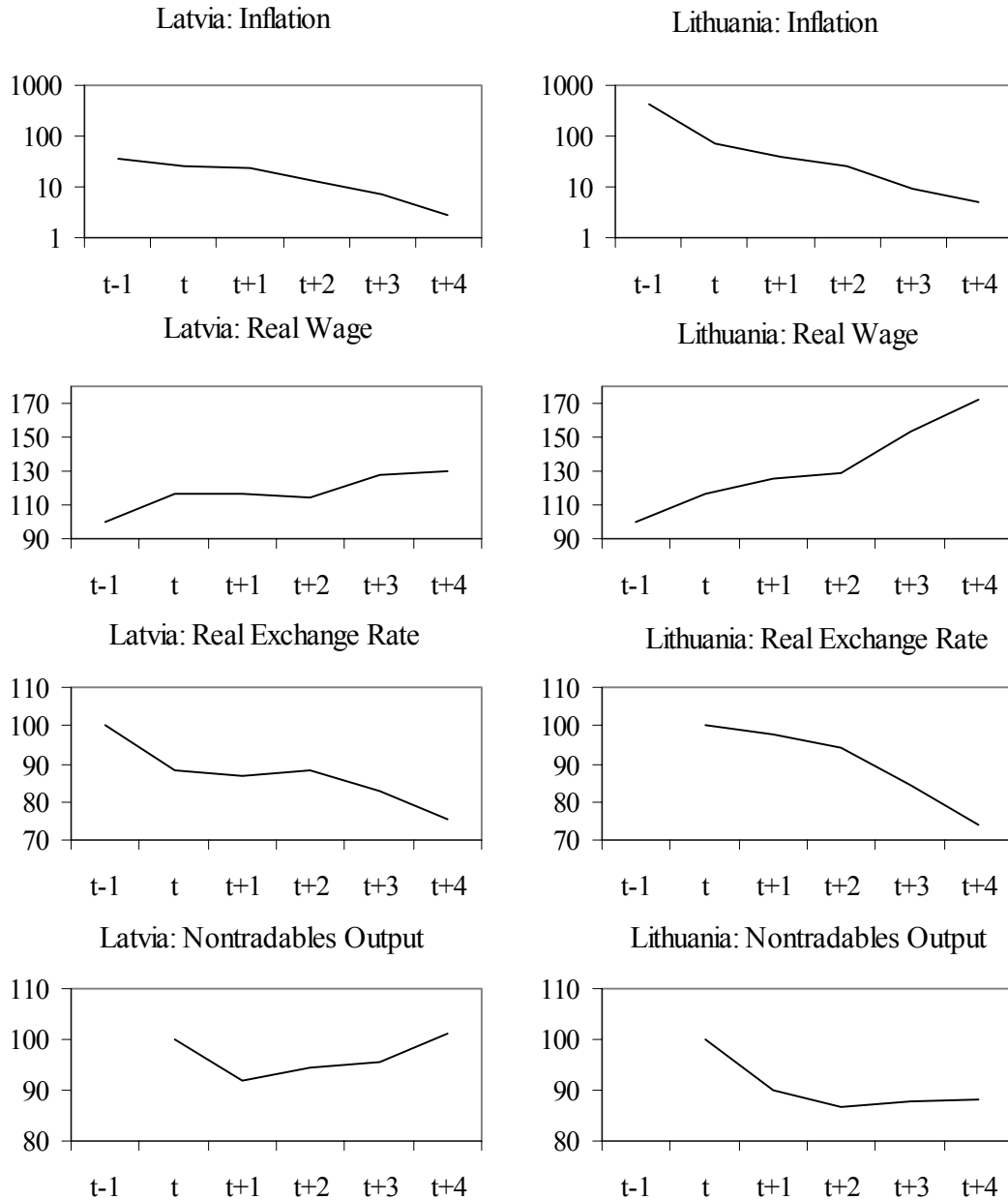
Figure 2: Selected Macroeconomic Indicators in Exchange-Rate-Based Stabilizations in Central and Eastern Europe: Bulgaria and Estonia



Sources: IMF, *International Financial Statistics (IFS)* ; and published IMF country reports.

Notes: Inflation is in percentage points on a logarithmic scale. The rest of the indicators are indices based on year $t-1$ or t , depending on data availability. Real wage is the private sector wage for Bulgaria, and the economywide wage for Estonia. The exchange rate is the real effective exchange rate from *IFS* . Nontradables output is the ratio of gross value added in construction and nongovernment services to the rest of the economy.

Figure 3: Selected Macroeconomic Indicators in Exchange-Rate-Based Stabilizations in Central and Eastern Europe: Latvia and Lithuania



Sources: IMF, *International Financial Statistics (IFS)* ; and published IMF country reports.

Notes: Inflation is in percentage points on a logarithmic scale. The rest of the indicators are indices based on year $t-1$ or t , depending on data availability. Real wage is the economywide wage for Latvia, and the private sector wage for Lithuania. The exchange rate is the real effective exchange rate from *IFS* . Nontradables output is the ratio of gross value added in construction and nongovernment services to the rest of the economy.

2.4. Welfare Analysis

The combination of lower inflation and higher conventional taxation produces certain welfare trade-offs. In the low-inflation steady state, the gain from the lower tax on money has to be evaluated against the cost of the larger income tax distortion. In addition, the stabilization-induced transitional recession imposes additional welfare losses. The metric of compensating variation introduced by Lucas (1987) can be used to evaluate this trade-off. The net welfare gain resulting from the set of stabilization policies $\{\varepsilon^l, \tau^h\}$ compared with the original policy set $\{\varepsilon^h, \tau^l\}$ is computed as the fraction by which consumers' original steady state consumption basket would have to be increased to make them indifferent between their lifetime utility in the high-inflation steady state and the lifetime utility achieved along the equilibrium path to the new, low-inflation steady state. Thus, the welfare gain, χ , is determined from

$$\begin{aligned} & \int_0^\infty \left[\gamma \ln(\bar{c}^*) + (1 - \gamma) \ln(\bar{c}^h) + \theta \frac{(\bar{m}^h)^{1-\frac{1}{\beta}}}{1-\frac{1}{\beta}} - \kappa \frac{(\bar{L}^h)^{1+\frac{1}{\mu}}}{1+\frac{1}{\mu}} + \ln\left(1 + \frac{\chi}{100}\right) \right] e^{-rt} dt \\ = & \int_0^\infty \left[\gamma \ln(c_t^*) + (1 - \gamma) \ln(c_t) + \theta \frac{m_t^{1-\frac{1}{\beta}}}{1-\frac{1}{\beta}} - \kappa \frac{L_t^{1+\frac{1}{\mu}}}{1+\frac{1}{\mu}} \right] e^{-rt} dt . \end{aligned} \quad (53)$$

Needless to say, a positive number means that the new set of policies is preferable to the previous one. For the one-shot permanent disinflation described in the previous section, this measure produces a welfare gain of 0.751 percent. The benefits of the lower tax on money and less labor outweigh the loss of consumption resulting from the tax hike of roughly four percentage points. The difference in one-period utility between the new and the old steady state is

$$U^l - U^h = (1 - \gamma) \ln \frac{\bar{c}^l}{\bar{c}^h} + \frac{\theta \left((\bar{m}^l)^{1-\frac{1}{\beta}} - (\bar{m}^h)^{1-\frac{1}{\beta}} \right)}{1 - \frac{1}{\beta}} - \frac{\kappa}{1 + \frac{1}{\mu}} \left[\left(\frac{\bar{c}^l}{B} \right)^{1+\frac{1}{\mu}} - \left(\frac{\bar{c}^h}{B} \right)^{1+\frac{1}{\mu}} \right] = 0.0076, \quad (54)$$

where the superscripts l and h denote the low-inflation and the high-inflation steady states, respectively. So the steady state welfare gain more than covers the cost of the transitional recession. We will revisit this issue in Section 5.

2.4.1. Sensitivity of Welfare to Parameter Specification

It is interesting to analyze the welfare response to a varying interest elasticity of money demand, β , and wage elasticity of labor supply, μ . These parameters are important parts of the tax elasticities of money and labor, respectively. A well-established public finance result holds that it is optimal to tax more heavily the good with a lower tax elasticity. A sensitivity analysis with respect to β and μ will thus reveal to what extent the welfare gain resulting from the shift in taxation from money to income depends on the chosen parameter configuration. From (1) and (10), the tax (inflation) elasticity of money is

$$\frac{\partial \ln m_t}{\partial \ln \varepsilon_t} = -\frac{\beta \varepsilon_t}{r + \varepsilon_t}, \quad (55)$$

which is increasing in β in absolute value. From (11), (12), (36), (37), and the steady state condition that the wage is equal to the marginal product of labor ($\bar{w} = B$), labor supply can be expressed in the steady state as

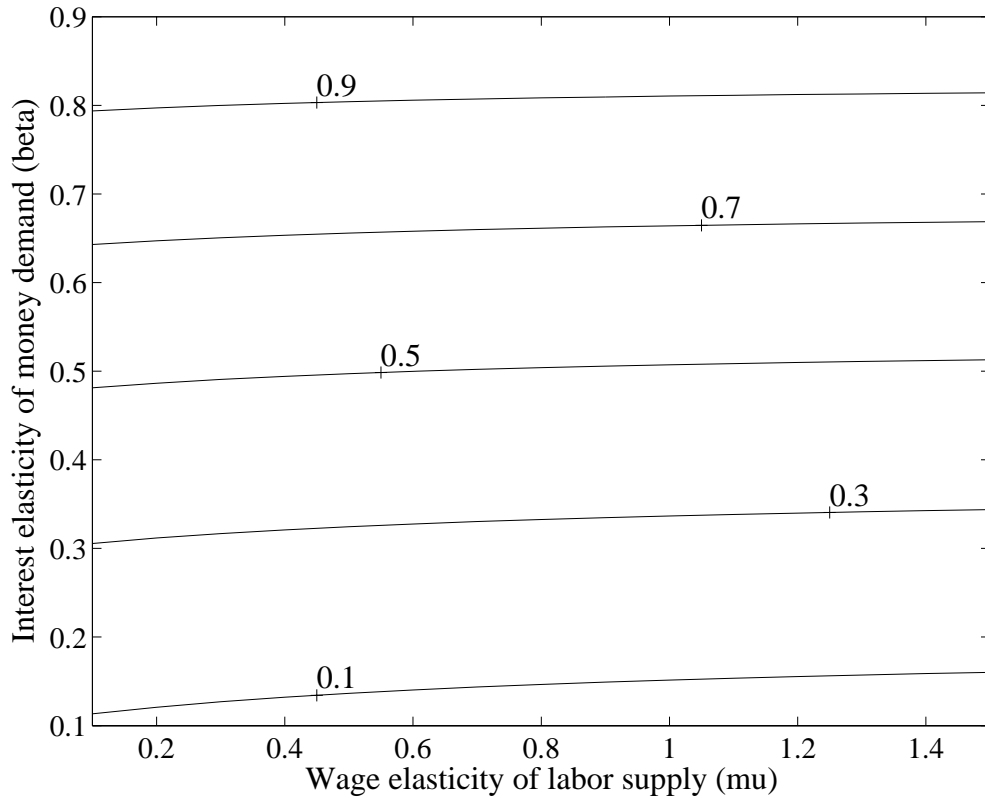
$$\bar{L} = \left(\frac{(1 - \gamma)(1 - \bar{\tau})}{\kappa} \right)^{\frac{\mu}{1+\mu}}, \quad (56)$$

and its income tax elasticity is

$$\frac{\partial \ln \bar{L}}{\partial \ln \bar{\tau}} = -\frac{\mu}{1+\mu} \frac{\tau}{1-\tau}, \quad (57)$$

which is increasing in μ in absolute value as well.¹⁸ Figure 4 shows the net utility gain contours under a permanent and instantaneous stabilization as a function of β and μ .

Figure 4: Welfare Gains As a Function of μ and β (in percent)



The welfare gain remains positive for all β and μ in the analyzed ranges. The strong sensitivity of the welfare gain to β is not surprising, as a larger β elicits larger money demand response to the sharp and immediate cut in inflation and thus raises welfare

¹⁸Outside the steady state, the tax elasticity of labor cannot be expressed analytically, as the real wage differs from the marginal product of labor because of the distortion created by the sticky inflation (see (51)).

considerably. The link to μ is much less pronounced, with the welfare gain declining slightly as more elastic labor supply leads to a larger drop in output (and thus consumption) in response to the higher tax rate. Clearly, welfare responds much less to variations in μ than in β , and in this sense labor is a less elastic good than money for a given r , ε^l , and τ^l . Thus, by shifting the burden of taxation from money holdings to labor income, stabilization indeed improves welfare for wide ranges of β and μ .

It follows from (55) and (57) that the tax elasticities of money and labor also depend on the international interest rate, r , and the initial size of government, τ^l , respectively. The welfare gains decrease notably in r and less so in τ^l . A real interest rate higher by 1 percentage point reduces the welfare gain by almost 1 percentage point via two channels: it lowers the money response to the cut in inflation, as well as discounts the future more heavily, thus giving a larger weight to the bigger short-term output transition losses relative to the smaller steady state ones. Regarding the initial taxation level, a 5-percentage-point-of-GDP higher initial government intake reduces welfare by 0.5 percentage point. As higher τ^l raises the tax elasticity of labor, the output loss is slightly bigger for a given reduction in inflation.

The welfare results are also positively related to the weight of money in the utility function, θ . The parameter θ is related to the degree of monetization of the economy, as explained in Section 3.1. Welfare turns negative only for extremely small values of θ (below 0.00001), corresponding to a money-to-GDP ratio of below 1/3 of 1 percent.

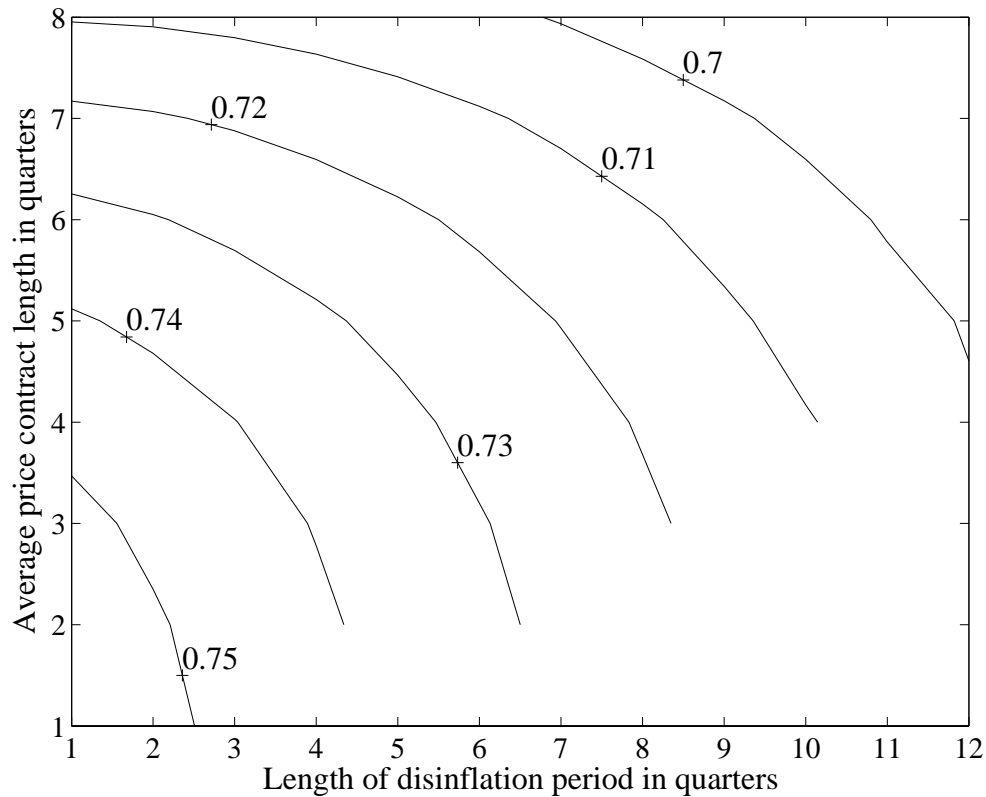
2.4.2. Sensitivity of Welfare to Speed of Disinflation and Degree of Price/ Inflation Stickiness

It is natural to ask how welfare comparisons depend on the policy design and/or the structural features of the economy. To this end, we repeat the sensitivity analysis in Calvo, Celasun, and Kumhof (2003), varying the speed of disinflation and the degree of price/

inflation stickiness. Specifically, the speed of disinflation is operationalized by considering gradual disinflation policies of the form $\dot{\varepsilon}_t = -\eta$ until $\varepsilon_t = \varepsilon^l$, where the parameter η characterizes the speed of disinflation, while the degree of price/inflation stickiness is given by the average duration of price contracts $1/\delta$. The results are presented in Figure 5. The figure shows that, for an empirically relevant average price contract length of about two-four quarters, halving inflation from 20 percent to 10 percent per annum produces net welfare gains of 0.71 - 0.75 percent. These gains are decreasing in the degree of price/inflation stickiness $1/\delta$, because the latter slows the response of the nontradable sector to the lower depreciation rate, thus deepening and prolonging its recession. They are also decreasing with a more gradual disinflation, despite the smaller loss of inflation tax revenue, which requires a lower increase in conventional taxation and thus provides for a shallower recession. The reason is that money increases by less in response to only a gradual cut in the interest rate, which effect dominates the gain from higher consumption. In addition, gradualism prolongs the transition to the relatively beneficial low-inflation steady state, an effect especially pronounced at a low degree of price stickiness as demonstrated by the steeper contours.

The tax rate necessary to offset the loss of inflation tax revenue comes in at 28.2–29.4 percent for various values of δ and η , about 3.5 - 5 percentage points higher than in the high-inflation steady state. This is at the low end of the range of observed tax revenue increases listed in Table 1, mainly because these countries needed more revenue to finance their increased expenditure, while the model assumes constant expenditure. The tax rate is not very sensitive to either the speed of disinflation or the degree of stickiness, because it is set such that the government's assets are stationary *in the new steady state*, while both δ and η affect primarily the transitional dynamics.

Figure 5: Welfare Gains As a Function of η and δ (in percent)



2.5. Sticky Prices Versus Sticky Inflation

Another interesting dimension of the analysis is what is the impact of the transitional recession generated by sticky inflation (the ability of firms to choose their inflation rate between price updates in addition to their price). To evaluate this, we recast the producer side of the model in terms of the conventional sticky price setting, where firms choose only their price upon getting the price-changing signal and update that price at the steady state inflation rate between signals (see Yun (1996)). For the purposes of this analysis, such sticky prices are analogous to flexible prices, as under a credible stabilization program both allow the economy to jump from the high-inflation steady state directly into the low-inflation one without a transitional recession.

Specifically, producers maximize

$$\text{Max}_{V_t} \int_t^\infty e^{-\int_t^s (\delta+r+\varepsilon_r-\pi_r)dr} \left[\frac{V_t e^{\bar{\pi}(s-t)}}{P_s} y_s (1 + sub) - w_s l_s \right] ds, \quad (58)$$

subject to the production function (12) and to the goods demand, which can now be expressed as

$$y_s = c_s \left(\frac{V_t^j e^{\bar{\pi}(s-t)}}{P_s} \right)^{-\sigma} \quad (59)$$

and substituted in (58).¹⁹ The first-order condition for V_t is

$$\int_t^\infty e^{-\int_t^s (\delta+r+\varepsilon_r-\pi_r)dr} c_s \left(\frac{V_t e^{\bar{\pi}(s-t)}}{P_s} \right)^{-\sigma} \left[\frac{V_t e^{\bar{\pi}(s-t)}}{P_s} - \frac{w_s}{B} \right] ds = 0.$$

Using again $p_t \equiv V_t/P_t$ and $P_s = P_t e^{\int_t^s \pi_r dr}$ for $s > t$, we can rewrite the last condition as

$$\int_t^\infty e^{-\int_t^s (\delta+r+\varepsilon_r-\pi_r)dr} c_s \left(p_t e^{-\int_t^s (\pi_r - \bar{\pi})dr} \right)^{-\sigma} \left[p_t e^{-\int_t^s (\pi_r - \bar{\pi})dr} - \frac{w_s}{B} \right] ds = 0. \quad (60)$$

As before, in the steady state we have $\bar{\pi} = \varepsilon^l$, $\bar{p} = 1$, and $\bar{w} = B$. We linearize (60) around the steady state and obtain the following expression:

$$p_t = (\delta + r) \int_t^\infty e^{-(\delta+r)(s-t)} \left[\frac{w_s}{B} + \int_t^s (\pi_r - \bar{\varepsilon}) dr \right] ds.$$

Its derivative with respect to time is

$$\dot{p}_t = (\delta + r) \left(p_t - \frac{w_t}{B} \right) - (\pi_t - \bar{\varepsilon}). \quad (61)$$

The aggregate price index (4) can now be rewritten as

¹⁹The firm index j is dropped, as the maximization problem is identical for all firms.

$$P_t = \left(\delta \int_{-\infty}^t e^{-\delta(t-s)} (V_s e^{\bar{\pi}(t-s)})^{1-\sigma} ds \right)^{\frac{1}{1-\sigma}} . \quad (62)$$

Taking its derivative with respect to time, we obtain

$$\pi_t = \frac{\delta}{1-\sigma} (p_t^{1-\sigma} - 1) . \quad (63)$$

Linearizing this expression around the steady state yields

$$(\pi_t - \bar{\varepsilon}) = \delta(p_t - 1) . \quad (64)$$

Its derivative with respect to time equals, using (61) and (64) itself,

$$\begin{aligned} \dot{\pi}_t &= \delta \dot{p}_t = \delta(\delta + r)(p_t - 1) - \left(\frac{w_t}{B} - 1\right) - \delta(\pi_t - \bar{\varepsilon}) \\ &= (\delta + r)(\pi_t - \bar{\varepsilon}) - \delta(\delta + r)\left(\frac{w_t}{B} - 1\right) - \delta(\pi_t - \bar{\varepsilon}) \\ &= r(\pi_t - \bar{\varepsilon}) - \frac{\delta(\delta + r)}{B}(w_t - B) . \end{aligned} \quad (65)$$

This is the first dynamic equation. As the initial relative price of new price setters, p_t , is free to jump at the start of the stabilization program ($t=0$), aggregate inflation is a jump variable. The second equation — for the wage rate — is equation (51) from above.

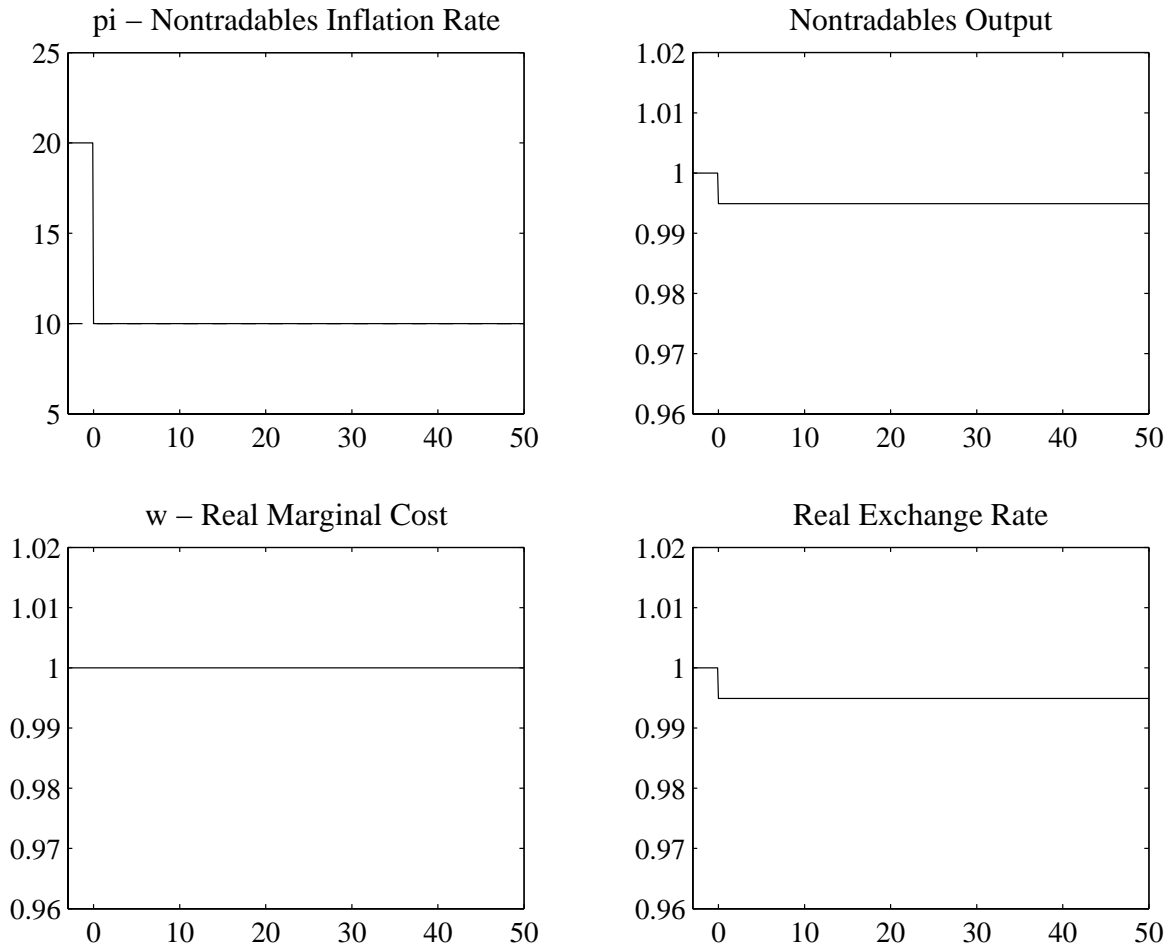
Thus, we have the following dynamic system:

$$\begin{bmatrix} \dot{\pi}_t \\ \dot{w}_t \end{bmatrix} = \begin{bmatrix} r & \frac{-\delta(\delta+r)}{B} \\ -B(1 + \frac{1}{\mu}) & 0 \end{bmatrix} \begin{bmatrix} (\pi_t - \bar{\varepsilon}) \\ (w_t - B) \end{bmatrix} + \begin{bmatrix} 0 \\ B(1 + \frac{1}{\mu}) \end{bmatrix} (\varepsilon_t - \bar{\varepsilon}) . \quad (66)$$

This system has one positive and one negative eigenvalue. With one free-jumping and one predetermined variable (see Section 2.5), it is saddle-path stable.

Figure 6 shows the dynamics of the main macroeconomic indicators. Under a cred-

Figure 6: Dynamic Paths of the Main Macroeconomic Indicators in the Sticky-Price-Only Case (in percent)



ible, permanent stabilization, the economy jumps directly in the new steady state and there is no transitional dynamics (see Calvo and Vegh, 1993). Inflation immediately falls to 10 percent, while the wage rate stays at its steady state value. Nevertheless, the economy contracts by about 0.5 percent again, as the loss of inflation tax revenue forces the fiscal authority to raise the income tax rate in order to balance the budget, which, in turn, lowers labor supply, consumption, and output of nontradables, and leads to a one-step real exchange rate appreciation. The welfare gain from the utility of larger money balances and

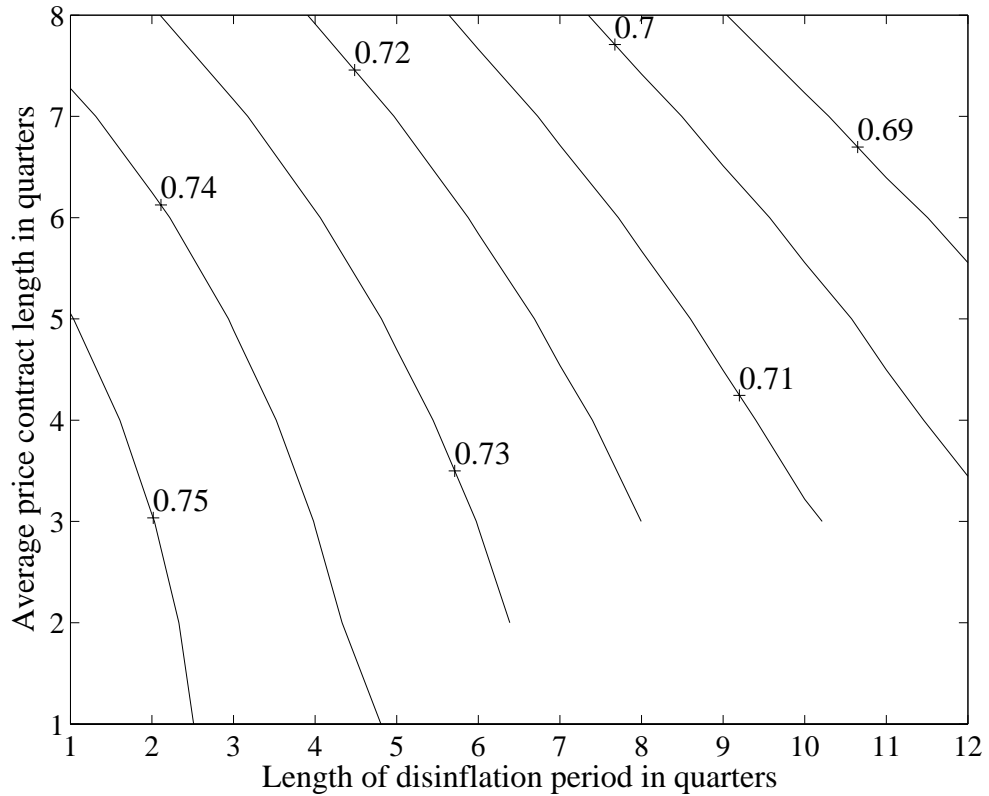
less labor outweighs the loss from lower consumption, for a net gain of 0.763 percent, about 0.012 percentage point higher than in the previously analyzed case of sticky inflation. The bulk of this difference comes from the lack of a transitional recession, while about 1/12 of it is due to the lower tax rate (28.88 percent now versus 29.04 percent before).

Figure 7 shows the welfare gains with varying speed of disinflation and degree of price stickiness. While the general shape and direction of the contours are similar to the ones in the sticky inflation case shown in Figure 5, for each combination of (η, δ) , the equilibrium tax rate is now lower, and the welfare gain is larger. Moreover, the contours are steeper, indicating that the welfare gain declines faster with gradualism than before. The reason for this is that firms now update their prices by the new steady state inflation rate ε^l between price-changing signals, and the more gradual the disinflation, the farther the exchange rate depreciation ε_t is from that steady state value, and the more the real exchange rate appreciates, causing a larger output loss.

Differences in the tax rates between these two exercises (here and in Section 4.2) are relatively minor, not extending beyond 1/4 of 1 percentage point on an annual basis. Generally, these differences rise in the degree of price stickiness (as less frequent price updates exacerbate the recessionary effects of sticky inflation and require a higher tax rate to balance the budget), and decline in the degree of gradualism (as a more gradual decline in the exchange rate depreciation rate allows for easier adjustment of inflation and thus reduces the harm of its stickiness).

Inflation stickiness is thus responsible for a small fraction of the necessary tax hike and the concomitant loss of output. The larger part of the tax increase is simply due to the need to replace the loss of inflation tax revenue in the steady state caused by disinflation. Nevertheless, by generating a transitional recession, sticky inflation further lowers the income tax base and necessitates a higher tax rate than otherwise to maintain fiscal sustainability. Thus, by further raising the tax rate in bad times, inflation stickiness makes fiscal

Figure 7: Welfare Gains as a Function of η and δ in the Sticky-Price-Only Case (in percent)



policy procyclical. This is a common feature in emerging markets and other developing countries, as documented and discussed in Kaminsky, Reinhart and Vegh, (2004).

2.6. Conclusion

This paper explores the implications of substituting conventional distortionary taxation for inflation tax revenue in a model of an exchange-rate-based stabilization with inflation inertia and an environment of optimizing agents. The need to raise taxes arises from the inflexibility of government expenditure, which cannot be cut to offset the loss of inflation tax receipts. To ensure the credibility of the stabilization program, the government

must find an alternative revenue source. The policy combination of lower inflation and the resulting higher conventional tax rate has in principle an ambiguous effect on welfare, as it pits the lower utility during the transition to the new steady state and the efficiency loss of the higher tax rate against the gains from the permanently smaller monetary distortion and smaller labor effort. The latter effects seem to dominate with these preferences and technologies, resulting in a net welfare gain. It therefore seems that, despite its adverse effect on output, higher conventional taxation is an acceptable substitute for inflation tax revenue in achieving a lasting and welfare-improving inflation stabilization.

3. Exchange-Rate-Based Stabilization Under Fiscal Constraints and Capital Controls

3.1. Introduction

The theory and practice of exchange-rate-based stabilization programs has been extensively analyzed in an effort to explain the reasons for the success or failure of these programs by features of their design and implementation.²⁰ The major lessons are that credibility and fiscal restraint matter most for success. Most models, however, make two crucial assumptions: (i) perfect capital mobility, which makes the real interest rate exogenous to the stabilizing economy; (ii) a sustainable fiscal position after the start of the stabilization program, which is shown to be a necessary, but not always sufficient condition for permanently lowering inflation.

Recognition of the powerful effects of global capital mobility is a distinctive feature in open-economy macroeconomics and international finance today. However, situations where capital mobility is low do still exist. A high-inflation economy in need of stabilization, possibly burdened by inherited debt, could be considered too high a credit risk and therefore could effectively be shut out of the international capital markets. While a complete absence of any capital movements is unlikely, especially in the presence of dollarization and volatile financial intermediation, domestic real interest rates are nevertheless endogenous — influencing and being influenced by the dynamics of consumption, money and government debt.

On the fiscal side, the obvious policy recommendation for successful stabilization is to reduce the deficit to a size that can be financed without much recourse to inflation tax. Most of the time, though, this is easier said than done. On the one hand, governments

²⁰See footnote 1 for a literature list.

face political constraints that could make a cut of the deficit below a certain level not only politically infeasible, but strategically unwise as well, leading to loss of political support and jeopardizing the success of the whole program. On the other hand, the burgeoning debt may break the stabilization on its own if not addressed. So countries with inflexible budgets face a dilemma — how to reconcile the loss of inflation tax revenue with the need to ensure the credibility of their stabilization policies.

Suppose a small open-to-trade economy with high debt burden and a history of heavy reliance on inflation-tax budget financing starts an exchange-rate-based stabilization program. There are sufficient foreign exchange reserves, so this type of stabilization looks feasible. However, the government cannot lower the primary fiscal deficit (or raise its primary surplus) beyond the existing level. This level is inconsistent with low inflation: given the prevailing interest rate, it puts the outstanding government debt on an explosive trajectory as in Sargent and Wallace (1981). What can this government do to save the stabilization effort?

Intuitively, lowering inflation at the onset of the stabilization program decreases the budget's inflation tax revenue. Other things being equal, the fiscal situation becomes unsustainable — the deficit starts increasing. The policy makers have, however, one more tool: an expansion of money supply by buying back government debt. The size of this operation ensures that the resulting dynamics of the real interest rate are consistent with convergence to the new, lower steady state debt level in a credible stabilization process. This policy has two desirable effects: (i) it lowers the real interest rate, which by itself lowers budget expenditures; (ii) it makes consumption and money demand (the inflation tax base) jump temporarily, raising additional budget revenues. If the stabilization program lacks credibility for whatever reason (i.e., it is perceived as temporary), the same policies as in the permanent case have different quantitative effects because consumers anticipate higher inflation in the foreseeable future and substitute current for future consumption.

Now the same monetary operation achieves much lower decline (if any) of the real interest rate at the start, and the latter quickly overshoots its steady state value. The fiscal "honey-moon" is much shorter. Since inflation acts as a distortionary tax, consumers' decisions are affected by inflation variability. The perfectly anticipated jump in inflation at the end of the stabilization program makes it optimal for the consumers to have a downward jump in their consumption/money holdings at this point, which results in an upward jump of the stock of government debt. The favorable temporary effects are completely reversed and the economy converges to its initial high-inflation equilibrium.

How do the dynamics of the main macroeconomic variables differ from the standard models of an exchange-rate-based stabilization (e.g., Calvo-Vegh, 1993 and 1994)? First, policy-induced changes in the real interest rate allow for temporary real effects in a permanent stabilization: consumption jumps up and then gradually decreases, the current account deficit does the same, the real interest rate drops and then converges back to its long-term level. Second, in a temporary stabilization, the effective price of consumption varies with the interest rate during the stabilization, which makes consumption vary as well — the smoothing, present in the constant interest rate models is absent. Third, a temporary stabilization is observationally very close to a permanent one — the only sign of trouble is the real interest rate overshooting its steady state level. Moreover, we show that, given consistency between the target inflation and the level of foreign exchange reserves and reasonably strict enforcement of capital controls, monetary policy can save an otherwise unsustainable stabilization program.

Analyses of the fiscal implications of an exchange-rate-based stabilization within this framework of continuous-time perfect foresight model and endogenous interest rates are provided in Velasco (1993) and Agenor and Montiel (1996). Velasco considers a similar question — how to use monetary policy to balance the budget if fiscal adjustment is infeasible — but only in the context of a permanent, credible stabilization. This paper

extends the analysis to temporary stabilization and considers similarities and differences in the transitional dynamics of the economy between both types of stabilization. Agenor and Montiel look at the effect of anticipated tax changes on the economy. They are not explicitly concerned with the dynamics of domestic government debt (in fact, they assume that it stays constant and normalize it to zero), while it is an important motivator of policy decision-making in our model.

3.2. The Model

3.2.1. Consumers

An infinitely living representative consumer maximizes utility subject to cash-in-advance and asset accumulation constraints. The model economy is small and freely trading, but closed for capital flows. The one consumption good is tradable. International prices are constant and normalized to one; continuous purchasing power parity (PPP) is assumed, so the domestic price level is given by the nominal exchange rate, E , and domestic inflation by the exchange rate depreciation. The exchange rate is predetermined, i.e., E cannot jump, but its rate of change, ε , can; however, it is constant between jumps. Output is constant. The assets available to the consumer are money and government bonds. The latter are inflation-indexed, to eliminate the government's temptation to inflate the debt away, which may lead to time inconsistency problems. There are transfers from the government, which are fixed at their pre-stabilization level. In standard notation, the consumer maximizes

$$\int_0^{\infty} u(c_t) e^{-\rho t} dt,$$

subject to:

$$m_t \geq \alpha c_t$$

$$\dot{a} = r_t a_t + \bar{y} + \bar{g} - c_t - (r_t + \varepsilon_t) m_t$$

where a_t denotes the consumer's assets, r_t is the domestic real interest rate, \bar{y} is the (constant) output and \bar{g} is the government's primary budget deficit, equal to the fiscal transfers net of any lump-sum taxes. Throughout the paper we assume that the nominal interest rate is positive, i.e. the cash-in-advance constraint is binding.

The first-order conditions are

$$u'(c_t) = \lambda_t (1 + \alpha(r_t + \varepsilon_t)), \quad (67)$$

$$m_t = \alpha c_t, \quad (68)$$

$$\dot{\lambda} = (\rho - r_t) \lambda_t, \quad (69)$$

$$\dot{a} = r_t a_t + \bar{y} + \bar{g} - c_t - (r_t + \varepsilon_t) m_t, \quad (70)$$

$$a_t e^{-\int_0^t r_s ds} \rightarrow 0, \quad t \rightarrow \infty. \quad (71)$$

Condition (67) says that along the optimal consumption path, marginal utility of current consumption is equal to its cost — the foregone utility from wealth accumulation, which could have been used for future consumption. The term $1 + \alpha(r_t + \varepsilon_t)$ is the *effective price of consumption*: the market price (one) plus the opportunity costs of holding money. Condition (68) establishes the money demand function. The third one gives the law of motion of the marginal utility of wealth. The fourth one is again the consumer asset-accumulation equation. The no-Ponzi-game condition in the end is actually a constraint on both the consumer and the government: it implies that the consumer cannot accumulate bonds or money without bound; therefore, the government cannot issue bonds forever.

3.2.2. Government

The government issues bonds and collects inflation tax to cover its deficit.²¹ Its debt accumulation equation is

$$\dot{b} = r_t b_t + \bar{g} - \varepsilon_t m_t.$$

Note that the primary budget deficit, \bar{g} , can be negative. Here b refers to bonds held outside the consolidated government. We also assume that real domestic credit growth is zero, so the fiscal authority gets only εm from money creation:

$$M = ER \Rightarrow \frac{\dot{M}}{E} = \varepsilon m + \dot{R}$$

The fiscal authority gets the first term, while the central bank gets the second one, the change in reserves.

3.2.3. Equilibrium and Dynamic System

From equation (67), we have $c_t = c(\lambda_t, r_t, \varepsilon_t)$, with the signs of the partial derivatives shown below the variables.

Using the identity that government's supply of bonds must be equal in equilibrium to consumer demand, equation (68), and $\dot{m}_t = \dot{a}_t - \dot{b}_t$, we derive the following equilibrium asset accumulation equations:

$$\dot{b} = r_t b_t + \bar{g} - \alpha \varepsilon_t c(\lambda_t, r_t, \varepsilon_t), \quad (72)$$

$$\dot{m} = \bar{y} - c(\lambda_t, r_t, \varepsilon_t) \quad \text{or} \quad \dot{c} = \frac{1}{\alpha} (\bar{y} - c(\lambda_t, r_t, \varepsilon_t)). \quad (73)$$

Differentiating equation (67) with respect to time and dividing the differentiated

²¹The results easily generalize to an income and/or consumption tax.

equation by (67) again, we get (after simplifications)

$$\dot{r} = \frac{1 + \alpha(r_t + \varepsilon_t)}{\alpha} \left(r_t - \rho + \frac{u''(c_t)}{u'(c_t)} \frac{1}{\alpha} (\bar{y} - c(\lambda_t, r_t, \varepsilon_t)) \right). \quad (74)$$

Let $u(c) = \log(c)$; then $\frac{u''(c)}{u'(c)} = -\frac{1}{c}$. Consider the following dynamic system:

$$\dot{\lambda} = (\rho - r_t)\lambda_t \quad (75)$$

$$\dot{r} = \frac{1 + \alpha(r_t + \varepsilon_t)}{\alpha} \left(r_t - \rho - \frac{\bar{y}}{\alpha c(\lambda_t, r_t, \varepsilon_t)} + \frac{1}{\alpha} \right) \quad (76)$$

$$\dot{b} = r_t b_t + \bar{g} - \alpha \varepsilon_t c(\lambda_t, r_t, \varepsilon_t) \quad (77)$$

This system has a steady state at:

$$\bar{r} = \rho; \quad \bar{b} = \frac{\alpha \bar{\varepsilon} \bar{y} - \bar{g}}{\rho}; \quad \bar{\lambda} = \frac{1}{\bar{y}(1 + \alpha(\rho + \bar{\varepsilon}))} \quad (78)$$

Let $P = 1 + \alpha(\rho + \bar{\varepsilon})$ be the effective price of consumption, evaluated at steady state. Linearizing the system around the steady state yields the following:

$$\begin{pmatrix} \dot{\lambda} \\ \dot{r} \\ \dot{b} \end{pmatrix} = \begin{pmatrix} 0 & -\frac{1}{\bar{y}P} & 0 \\ \frac{-P^2 \bar{y}}{\alpha^2} & \frac{P-1}{\alpha} & 0 \\ \alpha \bar{\varepsilon} \bar{y}^2 P & \bar{b} & \rho \end{pmatrix} \begin{pmatrix} \lambda_t - \bar{\lambda} \\ r_t - \rho \\ b_t - \bar{b} \end{pmatrix}.$$

Note that this system is partly recursive: the dynamics of λ and r affect those of b , but there seems to be no feedback. Nevertheless, the system has to be considered in its entirety for the following reason. The only free-jumping variable here is r . Because of the cash-in-advance constraint, consumption cannot jump without money jumping; therefore, absent money jumps, any jump of the marginal utility of wealth, λ , is supposed to exactly offset the jump (if any) in r . In the aftermath of a shock, if only one variable is allowed to

jump freely, the system may not be able to get on the convergent saddle path. Intuitively, there is no guarantee that the joint dynamics of r and λ (and thus $c(\lambda, r)$) will lead b towards the steady state, rather than to infinity.

The eigenvalues of the system's coefficient matrix are given by $v_1 = \rho$, $v_2 = \frac{\rho}{\alpha}$, and $v_3 = -\frac{1}{\alpha}$. Exactly one of these (v_3) is negative, thus the system has a unique convergent saddle path. The eigenvector corresponding to v_3 is (h_1, h_2, h_3) , where h_1 has been normalized to 1, $h_2 = \frac{P\bar{y}}{\alpha} > 0$ and $h_3 = \frac{-P\bar{y}(\alpha^2\bar{\varepsilon} + \bar{b})}{1 + \alpha\rho} < 0$. Thus, along the saddle path, the endogenous variables are related as follows:²²

$$\frac{\lambda_t - \bar{\lambda}}{b_t - \bar{b}} = \frac{h_1}{h_3} < 0, \quad \frac{r_t - \bar{r}}{b_t - \bar{b}} = \frac{h_2}{h_3} < 0, \quad \frac{\lambda_t - \bar{\lambda}}{r_t - \bar{r}} = \frac{h_1}{h_2} > 0. \quad (79)$$

In other words, the marginal utility of wealth and the real interest rate move together along the converging path, while government debt moves in the opposite direction. Remember that $c_t = c(\lambda_t, r_t)$. Thus, lower λ_t and/or r_t mean higher consumption and money, which means more tax revenues, allowing a higher level of steady state debt. Higher interest rates work, *ceteris paribus*, in the opposite direction. Finally, higher interest rate increases the effective price of consumption, and the resulting lower consumption is associated with higher marginal utility of wealth.

3.3. Policy Experiments

3.3.1. Permanent Stabilization

This policy experiment consists of two parts:

- An unanticipated decrease of the exchange rate depreciation from ε^h to ε^l (which is considered permanent by the consumers).

²²This follows from creating the ratios of the solution for the endogenous variables from the linearized system, ruling out the explosive components.

- An appropriate supporting policy (if necessary) to put the economy on a stable path converging to the low-inflation steady state.

Suppose that before the stabilization program starts, the system is in its high-inflation steady state (see equation 78). What is the reaction of the endogenous variables on impact? Denote the low-inflation steady state values by $\hat{\cdot}$ and the levels taken immediately after the start of the stabilization program by * . Along the convergent saddle path, the variables are related as follows:

$$\begin{aligned} (b^* - \bar{b}) + (\bar{b} - \hat{b}) &= \frac{h_3}{h_1}(\lambda^* - \bar{\lambda}) + (\bar{\lambda} - \hat{\lambda}) = \frac{h_3}{h_2}(r^* - \bar{r}) + (\bar{r} - \hat{r}), \quad (80) \\ (\lambda^* - \bar{\lambda}) + (\bar{\lambda} - \hat{\lambda}) &= \frac{h_1}{h_2}(r^* - \bar{r}) + (\bar{r} - \hat{r}). \end{aligned}$$

where the eigenvector components are evaluated at the low-inflation steady state.

The new, low-inflation steady state is

$$\begin{aligned} \hat{r} &= \bar{r} = \rho, \\ \hat{\lambda} &= \frac{1}{\bar{y}(1 + \alpha(\rho + \varepsilon^l))} > \bar{\lambda} = \frac{1}{\bar{y}(1 + \alpha(\rho + \varepsilon^h))}, \\ \hat{c} &= \bar{c} = \bar{y}, \\ \hat{b} &= \frac{\alpha\varepsilon^l\bar{y} - \bar{g}}{\rho} < \bar{b} = \frac{\alpha\varepsilon^h\bar{y} - \bar{g}}{\rho}. \end{aligned}$$

With the new steady state values, equation (79) simplifies to:

$$\begin{aligned} (b^* - \bar{b}) + \frac{a(\varepsilon^h - \varepsilon^l)\bar{y}}{\rho} &= \frac{h_3}{h_1} \left((\lambda^* - \bar{\lambda}) - \frac{a(\varepsilon^h - \varepsilon^l)}{\bar{y}P^h P^l} \right) = \frac{h_3}{h_2}(r^* - \bar{r}), \quad (81) \\ (\lambda^* - \bar{\lambda}) - \frac{a(\varepsilon^h - \varepsilon^l)}{\bar{y}P^h P^l} &= \frac{h_1}{h_2}(r^* - \bar{r}). \end{aligned}$$

These relationships will be used to determine the jumps at $t=0$, but first we need to define which variables can jump and under what circumstances. Since the nominal exchange rate (and hence the price level) is predetermined, b cannot jump on its own. To reach the new saddle path, both λ and r need to fall, but this would lead to an upward jump in c , which is precluded by the cash-in-advance constraint. The intuition is clear: since the targeted lower inflation can be supported only by a lower steady state debt level, the government needs to run a budget surplus for a while, in order to retire some debt from the current unsustainable level. However, since the tax rate (inflation) has gone down, there is a need to increase the tax base (money in this case). Here comes the role of the supporting policy: a money supply expansion by exchanging money for privately held bonds. Note that, as explained above, if cutting ε were the only policy change, the economy could not reach the converging saddle path. The intuition behind this is that the steady state determined solely by the $\dot{\lambda} = 0$ and $\dot{r} = 0$ equations does not necessarily involve $\dot{b} = 0$ too, given the pre-existing debt level \bar{b} ; in fact, this can happen only by coincidence. So an additional policy is needed to put the system on the stable path. Aside from adjusting the primary deficit down or a massive debt retiring (via external assistance, rescheduling etc., so that $\bar{b} = \hat{b}$), both of which we have ruled out, the only other feasible policy is lowering the real interest rate by adjusting money supply. This can only happen by purchasing bonds, the sole asset consumers hold, for money. The policy — purchases of government bonds by the central bank — is announced at the beginning of the stabilization program, so consumers take it into account, as required in a perfect foresight environment.

To illustrate this asset exchange, consider the balance sheets of the central bank, the fiscal authority, and the consolidated government on the eve of the stabilization program (Table 3).

Table 3: Balance Sheet of Government Entities in the High-Inflation Steady State

Central Bank		Fiscal Authority		Consolidated Government	
Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
\bar{R}	\bar{m}	$F\bar{T}$	b^{CB}	\bar{R}	\bar{m}
b^{CB}			\bar{b}	$F\bar{T}$	\bar{b}

Here \bar{R} is the foreign exchange reserves; \bar{m} base money; b^{CB} government bonds in the central bank portfolio; and \bar{b} government bonds held by the households.²³ Recall that the 'bar' values correspond to the high-inflation steady state. Revenues from "future taxation" (FT) is an item added to complete the fiscal authority's balance sheet, as government bonds are claims on future tax revenues.

Our policy experiment at $t=0$ can thus be summarized as:

- ε^h is decreased to ε^l , and
- \bar{m} is increased to m^* via the following operation:

1) the central bank begins net repurchases of bonds from the public, issuing new money for the purpose. This is reflected in its balance sheet as follows:

Central Bank: $\bar{R} + b^{CB} + \Delta b = \bar{m} + \Delta m.$

2) The fiscal authority's balance sheet remains unchanged:

Fiscal Authority: $F\bar{T} = b^{CB} + \Delta b + \bar{b} - \Delta b$

3) The consolidated government budget remains the same as well:

Consolidated Government: $\bar{R} + F\bar{T} = \bar{m} + \Delta m + \bar{b} - \Delta b.$ Note that the composition of government liabilities has changed: the share of money is up, while that of bonds is down. By size, $m^* - \bar{m} = \Delta m = \Delta b.$ The money supply value m^* can be derived from the asset exchange relationship $m^* - \bar{m} = -(b^* - \bar{b})$ at $t=0$, where b^* is among the solutions of the system:

²³Note that none of the increase in b_t^{CB} at $t=0$ goes to the fiscal authority, and central bank holdings of bonds stay constant thereafter.

$$\begin{aligned}
\frac{\lambda^* - \hat{\lambda}}{b^* - \hat{b}} &= \frac{h_1(\varepsilon^l)}{h_3(\varepsilon^l)} \\
\frac{r^* - \hat{r}}{b^* - \hat{b}} &= \frac{h_2(\varepsilon^l)}{h_3(\varepsilon^l)} \\
b^* - \bar{b} &= -\alpha(c^*(\lambda^*, r^*) - \bar{c})
\end{aligned}$$

After the operation, the balance sheets of the government entities look as follows:

Table 4: Balance Sheet of Government Entities Immediately After Start of Stabilization Program

Central Bank		Fiscal Authority		Consolidated Government	
Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
R	$m^* = \bar{m} + \Delta m$	FT	$b^{CB} + \Delta b$	R	m^*
$b^{CB} + \Delta b$			$b^* = \bar{b} - \Delta b$	$F\bar{T}$	b^*

Now, because money supply has increased, the real interest rate drops, and consumption jumps upward. Moreover, some debt is retired: $b^* - \bar{b} = -(m^* - \bar{m}) = -\alpha(c^* - \bar{c}) < 0$. The debt adjustment to the steady state is a combination of an immediate stock drop and a slow decline afterwards. The dynamics of the endogenous variables are shown in Figure 8.²⁴ We see that λ_t and r_t drop down to λ^* and r^* , respectively, which makes c_t jump upward to $c^* = \frac{m^*}{\alpha}$, using already provided money. The system gets on the new saddle path and converges to the new steady state. Government debt decreases — $\dot{b} < 0$ during this transition. The temporary consumption boom leads to a current account deficit (the top panel of Figure 11), financed out of the central bank reserves, which stay permanently lower thereafter.²⁵ Here we assume that the central bank has enough reserves to sustain the emerged current account deficit, i.e. the new inflation target, ε^l , is consistent

²⁴The phase diagrams in Figure 1 are projections of a three-dimensional phase dynamics space onto three two-dimensional phase planes.

²⁵For simplicity, we abstract from the interest income lost owing to decreased reserves.

with the level of reserves: $R_0 \geq \int_0^{SS} (\bar{y} - c(\varepsilon^l)) e^{-\rho t} dt$ where R_0 is the initial level of foreign exchange reserves and the international real interest rate is assumed to be equal to ρ .

The government agencies' balance sheets in the low-inflation steady state is shown in Table 5. As the money liability is the same in the two steady states, it follows that the loss of reserves during the transition from the high-inflation to the low-inflation steady state is equal to the size of the initial monetary push Δb . Nevertheless, this operation amounts to more than simply repaying some of the government debt with central bank reserves. It also lowers the real interest rate on the remaining debt and induces consumers to hold more money, thus expanding the inflation tax base.

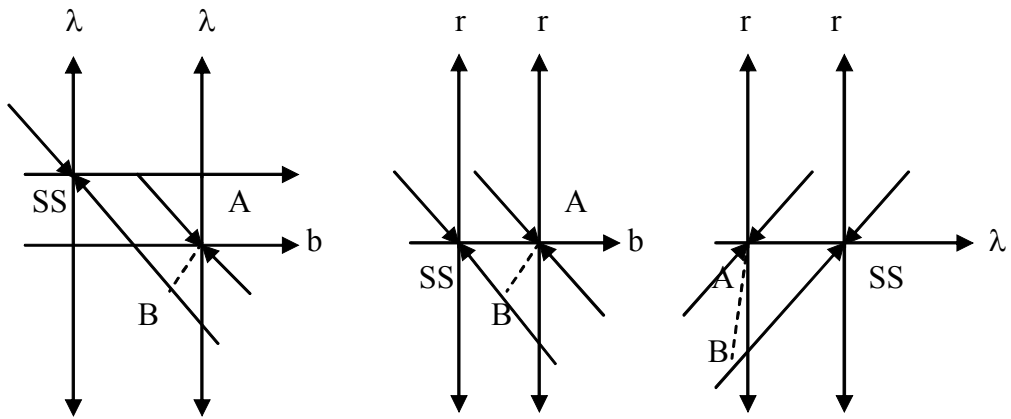
Table 5: Balance Sheet of Government Entities in the Low-Inflation Steady State

Central Bank		Fiscal Authority		Consolidated Government	
Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
$\hat{R} = \bar{R} - \Delta b$	$\hat{m} = \bar{m}$	$F\hat{T}$	$b^{CB} + \Delta b$	\hat{R}	\hat{m}
$b^{CB} + \Delta b$			\hat{b}	$F\hat{T}$	\hat{b}

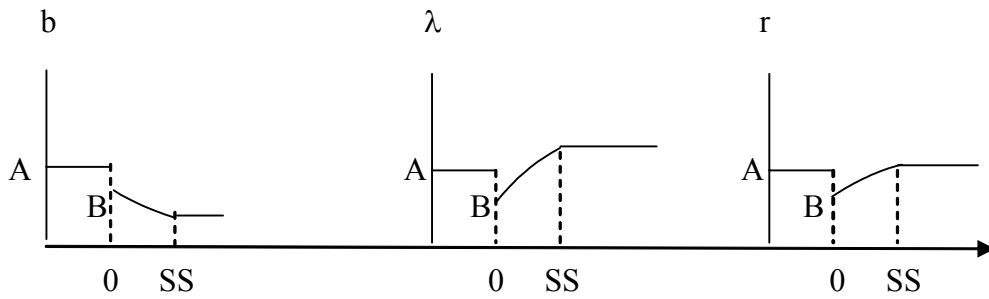
What is the intuition behind these dynamics? As long as the stabilization is considered permanent, if the decrease in the devaluation rate were the only policy change, the consumer would have no incentive to change consumption intertemporally — the effective price of consumption stays flat in the future. Technically, with unchanged money supply the only stable solution of the system $(\dot{\lambda}, \dot{r})$ is $r^* = \rho$, $\lambda^* = \hat{\lambda}$; therefore, $c^* = \bar{y}$, which leads to $\dot{b} > 0$ for $\varepsilon^l < \varepsilon^h$. However, the budget would become unbalanced — the revenue decline from lower inflation tax is not matched by a decrease in expenditure. So the government introduces one more policy action — a swap of bonds for money.

Figure 8: Permanent Stabilization

Phase Plane Dynamics



Temporal Dynamics



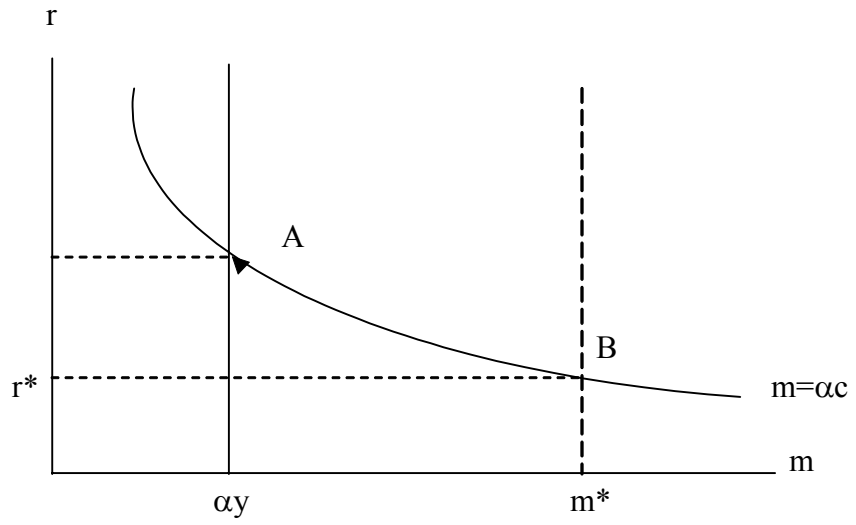
Look at the money market (the top panel of Figure 9). Most of the time, money supply passively follows money demand. At $t=0$, there is an exchange of asset stocks: bonds for money. Without this exchange, demand for money would not shift on its own at $t=0$: since the effective price of consumption appears flat, the forward-looking consumers would not change their consumption (and money demand) without an additional stimulus. This stimulus comes from the asset exchange: money supply shifts right. The equilibrium interest rate drops down, dragging the effective price of consumption with it; this causes an upward jump in consumption, financed by the already provided jump in money. Over time, the endogenous interest rate increases as the economy overheats, increasing the effective price of consumption. Hence, after the initial jump, consumption declines to its steady state.

Compare the permanent-stabilization solution of this model to the perfect capital mobility model (e.g., Calvo and Vegh, 1993 and 1994, Talvi, 1996). Because of the perfect capital mobility there, r cannot deviate from the international interest rate and c is constant — there is no room for additional discretionary policy. Here, policy can influence (temporarily) interest rates and thus consumption. The temporary current account deficit caused by this intervention does not jeopardize the sustainability of the stabilization, as long as it can be financed out of the monetary authorities' reserves.

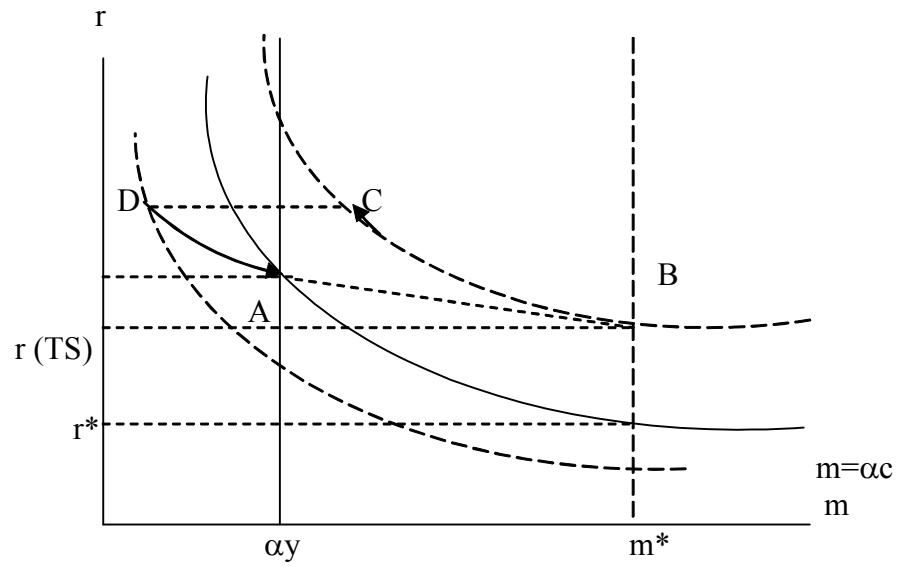
Admittedly, the practical implementation of the above-described operation is not easy. If money demand is unstable, a given increase in money supply may not result in the desired real interest rate. This can be remedied if the monetary authority sets the real interest rate and adjusts money supply in response to demand. In addition, capital controls usually leak, so part of the increased money supply may get immediately transformed in foreign exchange and thus not contribute to lowering the real interest rate. However, as long as domestic-currency assets yield more than foreign-exchange ones, this tendency should not persist in an otherwise credible stabilization program.

Figure 9: Money Dynamics

Permanent Stabilization



Temporary Stabilization



3.3.2. Temporary Stabilization

So far, we have been looking at the sustainable (permanent, credible) stabilization outcome; we showed that with the right policy package a permanent stabilization is feasible, despite the temporary boom in domestic demand. Now suppose that the public is skeptical about the government's long-term commitment to stabilization. They expect the government to revert to high-inflation policies at some point in the future. In perfect foresight, this point is known from the beginning of the stabilization attempt.

At the launch of the stabilization program, the policymakers cannot tell if the public expects it to be permanent or temporary. So they act as in the permanent case and send the same policy signals at $t=0$:

- ε^h is decreased to ε^l , and
- the same open-market operation is repeated: \bar{m} is increased to m^* , \bar{b} drops to b^* .

As, however, consumers believe the decrease in inflation will be only temporary, the signals they receive are

- ε^h is decreased to ε^l for a period $(0, T)$, after which it is restored to ε^h . The end-date T is exogenously given and known to the consumer;²⁶
- \bar{m} is increased to m^* , \bar{b} is decreased to b^* .

For expositional simplicity, let us split the effects of the above policies. First, consider the movements of the depreciation rate. Now, even without any other policy change,

²⁶Endogenizing T by making the stabilization crash when b_T reaches certain level (say, its original level \bar{b}) leads to non-uniqueness. The shorter the expected T , the higher is consumption in $[0, T]$ (as the life-time budget constraint of the consumer is unchanged), as well as the real interest rate. These two developments result in opposing effects on debt dynamics, but it can be shown under reasonable assumptions that the interest rate effect dominates. Thus, debt grows faster if expected T is shorter, so the crisis level b_T is hit earlier. Therefore, expected shorter T leads to actual shorter T ; since expectations are exogenous, non-uniqueness follows.

the effective price of consumption jumps with inflation at T . So the consumers have a reason to substitute consumption intertemporally, which reason alone is sufficient to trigger a jump in consumption up at $t=0$ and down at $t=T$. Now look at the money market again (the bottom panel of Figure 9). Since consumption jumps up at $t=0$ and down at $t=T$, money demand does the same (from point A to B at $t=0$, and from C to D at $t=T$). Note the difference from the permanent stabilization case, where this effect is not present.

Second, money supply goes up at $t=0$ by policy design and down at $t=T$ as unwanted money balances are converted to bonds. The net effect on the interest rate at $t=0$ is ambiguous: it depends both on the intertemporal elasticity of consumption substitution (IES) and the expected duration of the stabilization effort, T , via the consumer's life-time budget constraint. Empirical evidence points to low IES (Reinhart and Vegh, 1995); moreover, if a stabilization program is being discussed at all, its credibility has to be considerable at least in the eyes of the policymakers, which is proxied by long T . Suppose, therefore, that the IES is relatively low and T is expected to be long enough, so money demand jumps by less than money supply and r drops down a bit (still, it always stays above r^* in the permanent stabilization case, because money supply shifts by the same amount as before, while money demand shifts up autonomously now). On impact, consumption jumps to the same point c^* as in the permanent case because money jumps again to m^* and the cash-in-advance constraint is binding. We also find that $\dot{b}|_{TS} > \dot{b}|_{PS}$ — debt grows faster under a temporary stabilization (TS) than under a permanent one (PS). ($\dot{b}|_{TS} = r^{TS}b^* + \bar{g} - \alpha\varepsilon^l c^* > \dot{b}|_{PS} = r^*b^* + \bar{g} - \alpha\varepsilon^l c^*$; since in TS r increases faster and c decreases faster than in PS, the relationship stays the same thereafter.) Actually, debt still decreases in the beginning, but much more slowly than what is needed to put the economy on a sustainable path.

Figure 10 shows the dynamics of the model variables. At $t=0$, bonds drop to b^* again and r drops slightly to r^{TS} . At $T+$ inflation shoots back up to ε^h and the system

has to be on the saddle path leading to the high-inflation steady state. Since consumers can exchange money for bonds on demand and the price level is predetermined, the real interest rate is continuous at T ; otherwise, there would have been intertemporal arbitrage opportunities. Also, because the crash has been anticipated, the real consumer wealth does not jump; therefore, the marginal utility of wealth, λ , is continuous at T . The jump of the economy between $T-$ and $T+$ is given by the following system:

$$u(c_{T+}) + \lambda_T r_T a_T + \bar{y} + \bar{g} - c_{T+} - (r_{T+} + \varepsilon^h) m_{T+} = u(\bar{y}) \quad (82)$$

$$\frac{\lambda_T - \bar{\lambda}}{r_T - \rho} = \frac{h_1(\varepsilon^h)}{h_2(\varepsilon^h)} = \frac{\alpha}{\bar{y} P^h} \quad (83)$$

$$\frac{b_{T+} - \bar{b}}{\lambda_T - \bar{\lambda}} = \frac{h_3(\varepsilon^h)}{h_1(\varepsilon^h)} = -\frac{1 + \alpha \rho}{\bar{y} P^h (\alpha^2 \varepsilon^h + \bar{b})} \quad (84)$$

$$b_{T+} - b_{T-} = -\alpha(c_{T+} - c_{T-}) = -\frac{\alpha^2(\varepsilon^l - \varepsilon^h)}{\lambda_T P^h P^l} \quad (85)$$

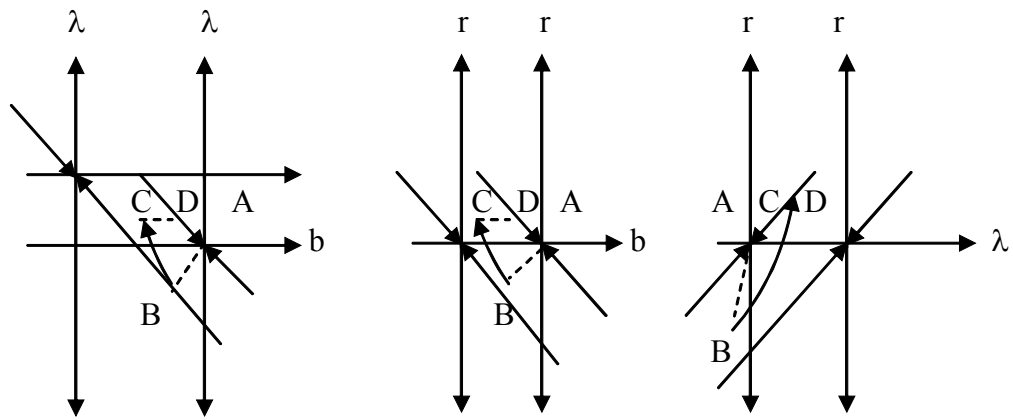
Equation (82) follows from the constancy of the Hamiltonian between $T+$ and the steady state. Equations (83) and (84) are the saddle-path relationships between the endogenous variables, derived in (79) — since the system has to be on the convergent trajectory to the high-inflation steady state at $T+$. Equation (85) follows from the asset-exchange requirement — unwanted money is exchanged for bonds at T — and the cash-in-advance constraint. The prices $P^h = 1 + \alpha(\rho + \varepsilon^h)$ and $P^l = 1 + \alpha(\rho + \varepsilon^l)$.

This system involves four unknowns: $\lambda_T, r_T, b_{T+}, b_{T-}$.²⁷ The end-date T and ε^h are exogenous, c_{T-} and c_{T+} can be derived from the first-order condition (67) at $T-$ and $T+$. Consumption jumps down, dragging money demand with it; because of that, government debt jumps up — unwanted money is exchanged for bonds. As can be seen in the bottom panel of Figure 11, the current account shifts from a deficit to a surplus.

²⁷Note that, using the cash-in-advance constraint, equation (67), and $a_t = m_t + b_t$, (82) can be written in terms of the four unknowns.

Figure 10: Temporary Stabilization

Phase Plane Dynamics



Temporal Dynamics

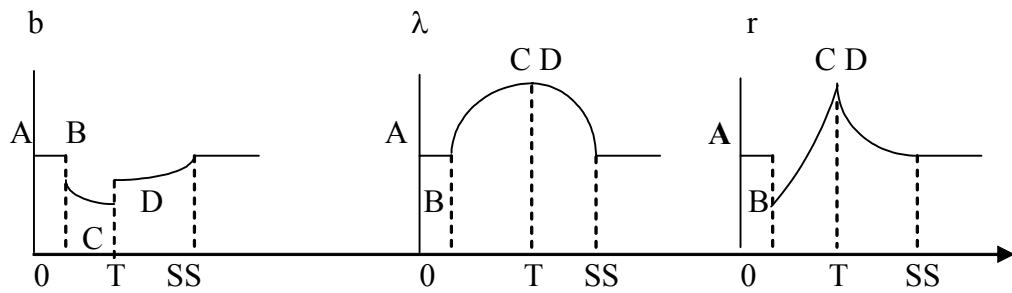
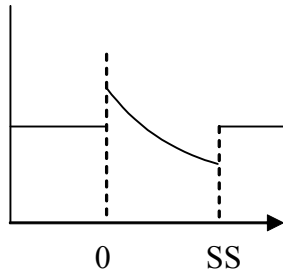


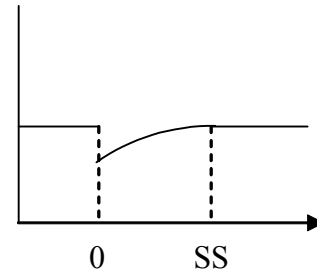
Figure 11: Time Paths of Consumption and Current Account Balance

Permanent Stabilization

Consumption

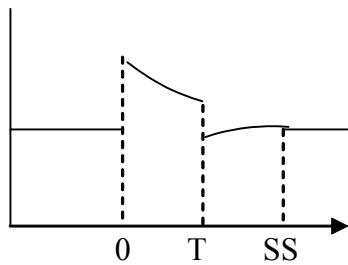


Current Account Balance

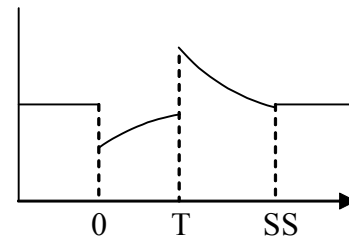


Temporary Stabilization

Consumption



Current Account Balance



To summarize the intuition, a temporary stabilization program looks sustainable for a while — the dynamics are almost like those in the permanent case: consumption jumps up and then gradually decreases, the interest rate does the opposite, and government debt decreases. This is the so-called Talvi effect in play — the temporary increase in the tax base provides a revenue boost, which masks the need for a genuine fiscal adjustment (Talvi, 1996). Even the current account deficit decreases with the declining consumption after the initial overshooting. But then, at some $t' < T$, the interest rate dynamics deviate from those in the permanent case — r goes above ρ and continues increasing; it becomes clear that the public do not expect the good times to last. The stabilization program ends at T with a consumption and money demand collapse (and then slow recovery), the real interest rate starts declining, debt still rises for a while, until reaching its stable (albeit high) equilibrium level.

So, with the help of the same-size one-time expansion in money supply, a temporary real boom is generated again. However, lack of credibility leads to different dynamics. The most marked difference is in the trajectory of the real interest rate, which overshoots its steady state level before the collapse.

3.4. Conclusion

In this paper, we have derived the following results. First, not surprisingly, in an economy where capital flows are restricted, economic policymakers have a degree of control over domestic interest rates. They can change the initial conditions of the economy by a one-time open-market operation, which lowers the real interest rate at the beginning of the stabilization program and thus ensures fiscal sustainability.

Second, the ability to influence interest rates does not substitute for credibility. If the program is not sufficiently credible at the start, monetary policy is only temporarily suc-

cessful in bringing the real interest rate and the fiscal deficit down. The initial interest rate push is quickly overturned, and the real interest rate overshoots its steady state value before the crash of the program. Thus, it can serve as a early warning signal that stabilization is in peril.

Third, owing to the real interest rate variability that affects the effective price of consumption, the economy experiences a temporary consumption boom, accompanied by a current account deficit in both the permanent and the temporary stabilization cases. This emphasizes the need for a sufficient amount of reserves (or a guaranteed access to low-interest loans, for example from the multilateral financial institutions) at the start, for the government to be able to afford the described set of policies.

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