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THE BUSINESS CYCLES OF BALANCE-OF-PAYMENTS CRISES: A REVISION OF A MUNDELLIAN FRAMEWORK[1]

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In a seminal 1960 article Robert Mundell proposed a model of balance-of-payments crises in which confidence in the continuation of a currency peg depended on the observed holdings of foreign reserves. We examine the implications of a reformulation of this view from the perspective of an equilibrium business cycle model in which the probability of devaluation is an endogenous variable conditioned on foreign reserves. The model explains some business cycle regularities of exchange-rate-based stabilizations while also producing devaluation probabilities that capture some features of those estimated in the data. The analysis aims to explain both the real effects and the collapse of temporary fixed-exchange-rate regimes in an unified framework, and provides an economic interpretation for the evidence that foreign reserves are a robust leading indicator of currency crises.

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"The confidence that once prevailed in the permanence of the existing exchange parity no longer exists...Fear of inconvertibility or devaluation often swamps the effects of small differences in rates of interest between money markets, and encourages capital outflows. But confidence is generally linked to the level of exchange reserves. Other things the same, confidence is higher the larger the central bank holdings of foreign exchange"

(Robert A. Mundell, (1960), pp.227-257)

1. Introduction

In a path-breaking paper that originated in his doctoral dissertation, "The Monetary Dynamics of International Adjustment under Fixed and Flexible Exchange Rates" (QJE, May 1960), Robert A. Mundell proposed an innovative framework that was the first to attempt an explicit treatment of macroeconomic dynamics under fixed and flexible exchange rates. Using the tools from Samuelson's *Foundations of Economic Analysis*, Mundell established a result that is now a classic principle: a fixed exchange rate may dominate a flexible exchange rate, in the sense of exhibiting better stabilizing properties in the face of exogenous shocks, if there is a high degree of international capital mobility. The apparatus he developed to derive this result was the backbone of the Mundell-Fleming model, which remained the dominant paradigm in international macroeconomics for the next 25 years.[1]

We argue in this paper that, in the light of the globalized economy we live in today, Mundell's article contains another pioneering contribution: the first formal dynamic analysis of balance-of-payments crises. His analysis included some of the key ingredients of the classic models of balance-of-payments crises developed much later by Krugman (1979) and Obstfeld (1986). He explicitly asked the same question that models of this kind continue to raise today:

"to what extent can offsetting central bank action stabilize a system which is inherently unstable because of speculative capital movements?" (Mundell (1960), p.228). Mundell examined this question in the context of a fixed-exchange-rate economy where the investors' confidence in the currency is positively related to the central bank's holdings of foreign reserves, and studied how this affected the equilibrium determination of the interest rate and the price level. His key finding was that the dynamics of adjustment could be stable or unstable, cyclical or asymptotic depending on the relative size of two "response" parameters: (a) the parameter governing the offsetting response of economic policy to a surge in private capital outflows and (b) the parameter that determines the magnitude of a surge in these outflows in response to an observed decline in foreign reserves. An economy where the second parameter is sufficiently larger than the first would exhibit unstable or cyclical dynamics, whereas an economy with the opposite feature would exhibit stable, asymptotic dynamics.

In the environment of highly restricted capital flows of the 1960s, Mundell's exploration of balance-of-payments crises seemed of little relevance compared to his findings regarding the stabilizing properties of fixed exchange rates. Hence, his analysis of speculative capital flows was largely ignored in the large literature that followed the Mundell-Fleming model. Today, however, the situation is the opposite. The case of limited capital mobility is at best a teaching tool, and perfect or near-perfect capital mobility is the framework from which academic and policy discussions start. Recurrent episodes like the collapse of the ERM in Europe, the Mexican crisis of 1994, the South East Asian crises of 1997, the collapse of the Russian ruble in 1998 and the recent collapse of the Brazilian real illustrate the key relevance of the analysis of speculative attacks in an environment of highly integrated capital markets.

This paper re-formulates Mundell's analysis from the perspective of modern international macroeconomics. Like Mundell, we study the dynamics of an economy where the likelihood that a currency peg will be maintained depends on the stock of foreign reserves. In contrast with his analysis, however, we examine a framework in which private agents formulate rational expectations of the possibility of abandonment of the peg. In equilibrium, these expectations will be consistent with the policy reaction function of the central bank. The latter is modeled to conform to a commitment to let the nominal interest rate be determined by uncovered interest parity, with a currency risk premium that evolves as a decreasing function of the stock of foreign exchange reserves. Hence, in equilibrium the rational expectations of devaluation of the private sector will also be a decreasing function of foreign reserves. Since changes in reserves are determined by the optimal plans of private agents, both the probability of devaluation and the currency risk premium will be endogenous outcomes of the model.

We borrow from Mundell's analysis the assumption that the central bank faces a borrowing constraint that imposes a minimum level of reserves below which the currency can no longer be pegged. Hence, balance-of-payments crises (i.e. situations in which reserves hit their critical level and force a devaluation) can emerge endogenously in this framework.

Our analysis also updates Mundell's in that the implications of the monetary dynamics of a fixed exchange rate for the real sector of the economy are derived as features of the general-equilibrium interaction of profit-maximizing firms and utility-maximizing households in an environment with uncertainty. Thus, the dynamics that lead to the collapse of a currency peg are accompanied by a "real business cycle." This monetary non-neutrality results from specifying a transmission mechanism in which the state-contingent distortions on the nominal interest rate that result from a time-varying currency risk premium create tax-like distortions on saving, investment and the supply of labor. Our aim in proceeding in this way is to capture the spirit of Mundell's framework, in which the dynamics of currency speculation are accompanied by output and price fluctuations. This approach also resembles that of real business cycle models driven by exogenous shocks, but it differs in that the underlying shock driving business cycles is monetary in origin and the stochastic process that describes it is endogenous.

The business cycle transmission mechanism that we study also features a state-contingent, fiscal-induced wealth effect similar to that identified by Calvo and Drazen (1993) in their study of uncertain duration of policy reforms.[2] This wealth effect is produced by the combination of two key assumptions: First, the government wastes seigniorage revenue in unproductive expenditures. A devaluation, therefore, entails the risk of a sudden fiscal expansion at the expense of private absorption. Second, markets of contingent claims are incomplete, so that private agents are unable to insure away the adverse wealth effect resulting from this sudden fiscal expansion.

It is important to note that, while considering intertemporal decision-making under uncertainty adds important elements that were missing from Mundell's analysis, intertemporal microfoundations are already commonplace in the modern literature on currency crises (see, for example, Calvo (1987), Drazen and Helpman (1988) and Obstfeld (1995)). For the most part, however, this literature has focused on the *qualitative* implications of the theory, seeking to establish whether these implications were in line with basic qualitative features of the data. Our aim is to build on this literature to explore the *quantitative* predictions of a model of currency crises under uncertainty and general equilibrium, exploring the extent to which the model can account for both the monetary dynamics of balance-of-payments crises and the business cycle facts associated with currency pegs.

The quantitative emphasis of our analysis is justified partly by necessity, since models with the features we described tend to be analytically untractable, forcing researchers to explore them with numerical methods. However, the main justification for the quantitative approach is not theoretical but empirical, and it relates to two major challenges faced by current research on the dynamics of currency pegs. These challenges are: (a) to develop models that can explain the business cycle regularities of fixed-exchange-rate regimes in high-inflation countries (as documented by Helpman and Razin (1987), Kiguel and Liviatan (1992), and Vegh (1992)) and (b) to rationalize recent findings on the robustness of leading indicators or predictors of the collapse of fixed exchange rates (see, for example, Kaminsky and Reinhart (1999)).

Exchange-rate-based stabilizations are characterized by three key stylized facts: the real exchange rate appreciates sharply, external deficits widen considerably, and output and domestic absorption boom. In addition, most plans end up failing with recessions predating currency collapses, periods of stability of the real exchange rate in between periods of sharp, rapid appreciation, and a high degree of correlation between private expenditures and the real exchange rate. Despite significant progress in developing models that can account for some of these observations from a qualitative standpoint, Rebelo and Vegh (1996), Mendoza and Uribe (1997), and Uribe (1997) have showed that the same models confront serious difficulties in explaining the quantitative features of the data. In particular, the models produce negligible consumption booms and real appreciations compared to actual observations, and the observed co-existence of a gradual real appreciation with a gradual consumption boom is a theoretical impossibility for most of the models that exist in the literature -- this is the *price-consumption puzzle* identified by Uribe (1998a).[3]

A series of recent empirical studies provide growing evidence indicating that a few key macroeconomic indicators are robust predictors of currency crises, in the sense of statistical causality . Studies like that of Kaminsky and Reinhart (1999), Klein and Marion (1997), or Frankel and Rose (1996) find that the real exchange rate, foreign reserves, and the current account deficit systematically predate the occurrence of devaluations. Thus, a framework that may account for the business cycle regularities of exchange-rate-based disinflations must also try to rationalize the evidence on the predictive power of leading indicators of currency crashes. In this paper, we study whether a model of business cycles driven by endogenous exchange-rate uncertainty can help us to rationalize both sets of stylized facts.

The focus on explaining simultaneously the dynamic monetary process that leads to a devaluation and the business cycle facts of exchange-rate-based stabilizations is aimed at developing a framework in which the two phenomena are joint equilibrium outcomes. This is done in an effort to connect two literatures that in general have approached each issue separately. For example, the large literature on "credibility" models initiated by Calvo (1986) explains the real effects of stabilization plans by studying optimal household behavior assuming a given date in which there is an exogenous and fully-anticipated collapse of the currency. Similarly, most models of speculative attacks inspired in the work of Krugman (1979) and Obstfeld (1986) study dynamics of reserve losses and devaluations without explaining the process that leads to exchange-rate vulnerability reflected in large external deficits or overvalued real exchange rates. Paradoxically, Mundell’s (1960) model was again unique in that it was explicitly aimed at studying the overall macroeconomic effects of currency speculation. Calvo (1987) and Drazen and Helpman (1988) are also exceptions that aimed to study both the real effects of exchange-rate-based stabilizations and the collapse of fixed exchange rates.

The results of our analysis suggest that the model we study can explain some of the empirical regularities of exchange-rate-based stabilizations. In particular, the model can produce an endogenous time path of devaluation probabilities roughly consistent with the J-shaped path estimated in several empirical studies (see in particular Blanco and Garber (1986) and Klein and Marion (1997)). These devaluation probabilities are consistent in equilibrium with a pattern of macroeconomic dynamics that is roughly in line with basic business-cycle features of the data, including the aforementioned price-consumption puzzle. Moreover, our model also produces results that resemble the findings of Mundell's work. In particular, the time path of devaluation probabilities and the characteristics of equilibrium dynamics depend heavily on the relative values of (a) the parameter that captures the response of capital outflows to changes in foreign reserves and (b) the parameter that captures the stance of fiscal policy. Economies where the former is sufficiently large relative to the latter exhibit an endogenous balance-of-payments crisis, and the crisis occurs sooner as the difference grows larger.

The remainder of the paper is organized as follows. Section 2 describes the model. Section 3 characterizes the equilibrium and discusses the numerical solution method. Section 4 examines the simulations of the model. Section 5 draws conclusions and policy implications.

2. The Model

The model we propose represents a two-sector small open economy in which competitive firms produce traded and nontraded goods using capital and labor, and capital is an accumulable, tradable factor of production. Factors of production are modelled as in the specific-factors framework of the trade literature, so as to simplify the analysis by preventing labor and capital from moving across sectors. Money balances are used to economize transactions costs. Households and firms have unrestricted access to a perfectly competitive world capital market, but markets of contingent claims are incomplete.

2.1. The Private Sector

Households are infinitely-lived and maximize the following expected utility function:

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{\left[C_t \left(1 - L_t^N - L^T\right)^{\rho} \right]^{1-\sigma}}{1-\sigma} \quad \textbf{(1)}$$

$$C_t = \left[\omega (C_t^T)^{-\mu} + (1-\omega)(C_t^N)^{-\mu} \right]^{-\frac{1}{\mu}} \quad \textbf{(2)}$$

Private consumption C_t is represented by the isoelastic aggregator of consumption of traded goods, C_t^T, and nontraded goods, C_t^N, defined in equation (2), with $1/1+\mu$ denoting the elasticity of substitution between traded and nontraded goods. Households supply labor to industries producing both goods. Labor is specific to each industry and is supplied inelastically to the industry that produces traded goods, in an amount equivalent to L^T units of "raw time." Labor supplied to the nontraded goods industry, L_t^N, and leisure are perfect substitutes, so that, normalizing the time constraint, leisure is simply defined as $1\text{-}L_t^N\text{-}L^T$. Leisure enters in multiplicative form in utility, with ρ governing the steady-state leisure-to-consumption ratio. Utility from consumption and leisure is represented by a constant-relative-risk-aversion function, with σ measuring both the coefficient of relative risk aversion and the inverse of the intertemporal elasticity of substitution in consumption. The parameter $\beta \in (0,1)$ is the subjective discount factor.

Households maximize (1) subject to the following two constraints:

$$B_{t+1} - (1 + r^*) B_t + (C_t^T + p_t^N C_t^N) + I_t = A_t^T (K_t^T)^{1-\alpha T} (L^T)^{\alpha T}$$
$$+ p_t^N A_t^N (K^N)^{1-\alpha N} (L_t^N)^{\alpha N} - \frac{\varphi}{2} (K_{t+1}^T - K_t^T)^2 - m_t V_t S(V_t) + \frac{m_{t-1}}{1 + e_t} - m_t + T_t \quad \textbf{(3)}$$

$$I_t = K_{t+1}^T - (1-\delta) K_t^T \quad \textbf{(4)}$$

In addition, agents are assumed to be subject to a no-Ponzi-game constraint. World asset trading is limited to one-period bonds B paying the time-invariant real interest rate r^* in units of the traded good. The uses of household income on the left-hand-side of (3) are purchases of traded and nontraded goods for consumption and investment, I, and changes in bond holdings net of interest. The relative price of nontradables is defined as p^N, and, since purchasing power parity (PPP) with respect to tradables holds, it also represents the real exchange rate. The sources of household income on the right-hand-side of (3) are factor incomes from industries producing traded and nontraded goods (net of capital-adjustment costs, transaction costs, and changes in real money balances) and government transfers.

Production functions are Cobb-Douglas. Capital is specific to each industry and is inelastically supplied to the nontraded sector in the amount K^N, facing a zero depreciation rate. Capital in the traded sector, K_t^T is a traded good and depreciates at rate δ. Capital-adjustment costs distinguish financial from physical assets to prevent excessive investment variability as in Mendoza (1995). Real money balances, m, are measured in terms of traded goods and enter the model as a means to economize transaction costs (as in Greenwood (1983,1984) and Kimbrough (1986)). Transactions costs per unit of private absorption are given by S, which is a convex function of expenditure velocity $V=(C^T+p^N C^N+I)/m$. Given PPP in tradables and constant foreign prices, *e* represents both the inflation rate of tradables and the depreciation rate. *T* is a lump-sum transfer from the government.

2.2 Government Policy

A key feature of equilibrium models of currency crises is the explicit link between fiscal and exchange-rate policies established by the government budget constraint. In our case, the probabilistic setting with incomplete markets implies that we must be explicit about the stance of both policies during the states of nature in which the currency remains fixed as well as in those that a devaluation occurs. The policy regime in our model is described as follows:

2.2.1 Exchange Rate Policy: The Central Bank's Policy Reaction Function

The exchange-rate policy we study is an exchange-rate-based stabilization program of uncertain duration. Specifically, we assume that before period zero the economy was in a "sustainable" exchange rate regime with a constant rate of depreciation equal to $e^h>0$. This regime was "sustainable" in the sense that e^h is consistent with a stationary equilibrium of the model, as described in the next section. At $t=0$, the government announces and implements a currency peg, so that $e_0=0$. As long as the peg lasts, the policy reaction function of the central bank is represented by a logistic stochastic process according to which the conditional probability of devaluation (or hazard rate), $z_t \equiv Pr[e_{t+1}>0|e_t=0]$ for $t\geq 0$, is given by:

$$z_t = \frac{\exp\left[\Gamma + \frac{\mathrm{B}}{\left(\frac{R_{t-1}}{Y_{t-1}}\right) - \left(\frac{R}{Y}\right)^{crit}}\right]}{1 + \exp\left[\Gamma + \frac{\mathrm{B}}{\left(\frac{R_{t-1}}{Y_{t-1}}\right) - \left(\frac{R}{Y}\right)^{crit}}\right]} \quad for \quad 0 \leq t < J-1, \; and \; z_t = 1 \quad for \quad t \geq J-1. \qquad \textbf{(5)}$$

Devaluation is assumed to be an absorbent state, so $Pr[e_{t+1} > 0 | e_t > 0] = 1$. In addition, it is assumed that there exists a date $J>0$ in which exchange-rate uncertainty ends and there is a devaluation with probability 1.[4] In equation (5), R represents central bank holdings of interest-bearing foreign reserves, Y is the economy's total output in units of tradables, and Β and Γ are exogenous parameters.

Equation (5) sets the probability of devaluation as a decreasing function of the observed gap between the lagged reserves-to-GDP ratio and a minimum critical value of this ratio. By conditioning the probability of devaluation on foreign reserves we aim to capture the crucial feature of Mundell's (1960) analysis, in which a decline in reserves triggers speculative capital outflows.[5] The parameter Β is intended to reflect the sensitiveness of these outflows to changes in reserves. We also specified (5) to make the model consistent with Krugman-style models of speculative attacks: if at any date t between 0 and $J-1$ the ratio R/Y hits the critical level, a balance-of-payments crisis occurs with probability 1 in period $t+1$. Note, however, that the policy reaction function also allows implicitly for the possibility of "surprise" devaluations between dates 0 and $J-1$ triggered by exogenous shocks, even if reserves have not been depleted to the critical level.

The last element of exchange-rate policy is the response to a currency crisis. When the currency peg collapses, there is a switch to a deterministic environment in which the exchange rate depreciates at a constant rate. We follow the typical assumption of the credibility literature based on Calvo (1986) that collapse implies a return to the same high rate of inflation and depreciation that reigned before the stabilization plan was implemented, e^h. Hence, the post-collapse depreciation rate is fixed for all devaluation states of nature at any date t. Since the depreciation rate will be shown to act like a distortionary tax in our model, this assumption plays a key role in ensuring that distortions affecting private-sector behavior are limited only to those related to the uncertainty regarding the duration of the peg, and not to the post-collapse realization of the depreciation rate. Moreover, since the post-collapse depreciation rate must be "sustainable" and identical across all states of nature, the collapse of the peg must be accompanied by a state-contingent adjustment in fiscal policy that makes that outcome consistent with intertemporal fiscal solvency, as we clarify later.

Given this structure of exchange rate policy, the logistic reaction function setting z_t can be interpreted alternatively as a reaction function determining the expected rate of currency depreciation under a fixed exchange rate (note that $E(e_{t+1}|e_{t=}0) = z_t e^h + (1-z_t)0 = z_t e^h$). Moreover, interest parity, assuming a constant world interest rate, implies that the reaction function can also be interpreted approximately as a reaction function for the nominal interest rate. In fact, if households were risk-neutral, the reaction function we specified is equivalent to a reaction function for the nominal interest rate (in this case, interest parity implies that the domestic interest rate equals the constant world interest rate plus expected depreciation).

2.2.2. Fiscal Policy

The linkage between exchange-rate policy and fiscal policy is captured by the following government budget constraint:

$$G_t + T_t + R_{t+1} = m_t - \frac{m_{t-1}}{1 + e_t} + m_t V_t \, S(V_t) + (1 + r*)R_t \qquad \textbf{(6)}$$

The government undertakes unproductive expenditures G, holds foreign reserves, issues money, and makes transfer payments to households, all in units of traded goods. Both seigniorage and transactions costs are assumed to be part of government revenue.[6] During the currency peg, G and T are fiscal policy choices governed by the rules defined below, and the dynamics of m and V reflect optimal plans of the private sector that are fully accommodated by the central bank. It follows, therefore, that while the peg is in place (6) determines the evolution of foreign reserves (i.e. the balance of payments) so as to satisfy the government budget constraint.

Fiscal policy is assumed to follow three rules. First, the government sets unproductive expenditures to match exactly current revenue from seigniorage and transactions costs:[7]

$$G_t = m_t - \frac{m_{t-1}}{(1 + e_t)} + m_t V_t S(V_t) \quad \textbf{(7)}$$

This rule, in conjunction with the assumption of incomplete insurance markets, implies that the model features the same state-contingent, fiscal-induced wealth effects as in Calvo and Drazen (1993) and Mendoza and Uribe (1997). A currency collapse leads to a surge in seigniorage and an increase in velocity, thereby inducing an expansion of unproductive government purchases. This simple rule allows us to develop a tractable extension of the solution method we proposed in our previous work to the case of endogenous probabilities studied here.

The second fiscal rule dictates that, while the currency peg is in place, total government outlays are constant and equal to a fraction κ of their pre-stabilization level:

$$e_t = 0 \quad \Rightarrow \quad G_t + T_t = \kappa(G_{-1} + T_{-1}) \quad \textbf{(8)}$$

Hence, (7) and (8) combined imply that while the exchange rate remains fixed, changes in G_t induce an offsetting adjustment in T_t so as to ensure that total outlays remain constant. This rule is required to ensure that the time path of reserves during a currency peg reflects only adjustments in private optimal plans regarding the velocity of circulation of money and money demand, and is not driven by arbitrary changes in the time path of government outlays. A similar assumption is a typical feature of models of currency crises. In Krugman (1979) or Calvo (1987), for example, government outlays are kept constant at the level they had before the peg began, and the focus is on determining the endogenous date in which reserves are depleted down to the critical level triggering a currency collapse. This scenario is included in our model (since $\kappa=1$ is not ruled out), but we also allow for the option that some fiscal adjustment may accompany the introduction of the peg. The size of this initial fiscal adjustment will be a key determinant of the duration of a fixed exchange rate regime, resembling results in Helpman and Razin (1987) and Drazen and Helpman (1988).

The third fiscal rule establishes that the collapse of the peg must be followed by adjustments in lump-sum transfers, so that, given the previous two rules and the assumption that e^h is "sustainable" regardless of the date in which collapse occurs, the government's intertemporal budget constraint holds. In particular, we allow for adjustments in lump-sum transfers after the state-contingent date of a currency crash that ensure that $lim_{t\to\infty} (1+r^*)^{-t}R_t=0$. This in turn ensures that, as long as (6) and (7) hold, the present value of transfers as of t=0 equals $(1+r^*)R_0$.

It is instructive to compare our fiscal and exchange-rate policy regime with the one assumed in Calvo's (1987) perfect-foresight equilibrium model of balance-of-payment crises. In Calvo's regime, government outlays take the same value before and after the collapse of the peg, and fiscal solvency is maintained through an endogenous increase in the depreciation rate at the time the peg is abandoned.[8] In contrast, in our regime the abandonment of the peg is accompanied by an exogenous increase in the depreciation rate that is constant across states of nature, and fiscal solvency is maintained via endogenous, state-contingent adjustments of government outlays. Under perfect foresight, both regimes are closely related. In fact, they induce identical dynamics if we consider a deterministic, endowment-economy version of our model in which the post-collapse depreciation rate is set at a value such that no post-collapse fiscal adjustment is required. However, under uncertainty the two regimes are quite different. The reason is that our regime uses non-distorting, state-contingent lump-sum transfers to make the post-collapse depreciation rate independent of the date in which the program is abandoned. In Calvo's regime, on the other hand, uncertainty would imply that the rate of depreciation after the collapse varies with the duration of the program, which would create an extra distortion affecting the nominal interest rate and through it all endogenous real variables of the model.[9]

3. Equilibrium and Numerical Solution

3.1. The Model's Monetary Transmission Mechanism

The first-order conditions that characterize the households' optimal choices in this model are identical to those obtained in Mendoza and Uribe (1997). Hence, we limit the discussion here to a brief description of their implications for macroeconomic dynamics. The model embodies three atemporal and three intertemporal optimality conditions. The three atemporal conditions equate: (a) the marginal utility of consumption of the numeraire good C^T with the marginal utility of wealth multiplied by the marginal cost of transactions (with the latter at equilibrium as an increasing function of the nominal interest rate, as shown below), (b) the marginal rate of substitution between C^T and C^N with the corresponding relative price, and (c) the marginal disutility of labor in the nontradables sector to its marginal benefit, which is equal to the real wage adjusted by the marginal cost of transactions. The three intertemporal conditions are Euler equations that equate the marginal costs and benefits of sacrificing a unit of tradables consumption and investing it in each of the three assets available in the economy: foreign bonds, real balances, and physical capital.

To study how exchange-rate uncertainty distorts the real economy, it is useful to examine the Euler equation for accumulation of real money balances, which can be written as follows:

$$S^{\prime}(V_t^L)(V_t^L)^2 \;=\; \frac{r^*}{(1 + r^*)} \;+\; \left[\frac{\lambda_{t+1}^H}{E_t[\lambda_{t+1}|e_t\!=\!0]}\right]\left(\frac{z_t e}{(1+e)(1+r^*)}\right) \qquad \textbf{(9)}$$

This equilibrium condition describes the behavior of velocity from the perspective of any date t in which the stabilization plan is in place, and hence the depreciation rate is at its low state e_t^L=0, with the corresponding state-contingent choice for velocity denoted V^L. Condition (9) reflects the fact that optimal money holdings are determined so that the marginal benefit of holding an extra unit of real balances, in the left-hand-side of (9), equals the opportunity cost of holding money in the right-hand-side -- which is also equal to the nominal interest rate factor: $i_t/(1+i_t)$. Moreover, equation (9) and the assumptions that S is convex and continuously-differentiable imply that in equilibrium V is an increasing function of i. This implies in turn that the marginal cost of transactions $h(i)$ (where $h(i_t) \equiv 1+S[V(i_t)]+V(i_t)S'[V(i_t)]$) is also increasing in i .

Equation (9) shows that this model features a differential between the domestic and world nominal interest rates (recall that world inflation is zero, so r* is also the world nominal interest rate) that reflects a risk-adjusted uncovered interest parity condition. The time path of the interest differential is determined by two effects: (a) changes in the expected rate of depreciation of the currency $z_t e$ and (b) changes in the marginal utility of wealth in the high-depreciation-rate state λ_{t+1}^H relative to its conditional mean $E_t[\lambda_{t+1}|e_t=0]$. The first effect reflects the standard expected-depreciation premium under risk-neutrality. The second effect magnifies that premium by incorporating a wealth effect that reflects the combined influence of risk-aversion and incomplete markets. We infer that the wealth effect magnifies the interest premium -- that is $\lambda_{t+1}^{H}/E_t[\lambda_{t+1}|e_t=0]>1$ -- because a return to high inflation increases seigniorage and unproductive government purchases and thus reduces wealth and increases the marginal utility of wealth.

The time-variant interest rate premium leads to changes in velocity and the marginal cost of transactions that distort saving, investment, and labor supply decisions. These distortions affect the margins of optimal decision-making in a manner analogous to stochastic taxes on factor incomes and the return on saving. As Mendoza and Uribe (1999) showed, the model's consumption Euler equation can be simplified to show that the ratio of marginal transaction costs between two contiguous periods (i.e., $h(i_t)/h(i_{t+1})$) is equivalent to a stochastic tax on the intertemporal relative price of consumption of tradables. Similarly, $h(i_t)$ can be shown to act as a tax on current labor income and $h(i_{t+1})$ can be shown to act as a random tax on capital income (specifically, on the marginal product of capital at $t+1$).

In addition to the tax-like distortions, devaluation risk introduces state-contingent wealth effects because of the unproductive use of government revenue and the assumption of incomplete insurance markets. These wealth effects affect both consumption and the supply of labor. Moreover, the random taxes on factor income distort the accumulation of capital and the time path of factor payments, and hence introduce state-contingent wealth effects that remain in place even when government revenue is fully rebated to households.

The fiscal-induced wealth effect at work in this model is similar to the one that drives the analysis of Calvo and Drazen (1993), but the distortions on the intertemporal consumption margin differ in a significant way. The wealth effect is produced by the fact that, given the incompleteness of insurance markets, each period that the currency peg continues results in an increase in permanent income by the amount of the foregone unproductive expenditures that would have been financed by the collapse of the peg and the switch to the high-inflation regime. This wealth effect will be stronger, favoring an upward-sloping consumption path, the lower the elasticity of intertemporal substitution in consumption (as Calvo and Drazen proved).

If government revenue were fully rebated, the devaluation would not induce an adverse wealth effect, but the distortion affecting the intertemporal relative price of tradables via state-contingent changes in the ratio $h(i_t)/h(i_{t+1})$ would still be present. This intertemporal distortion has two important features that differ from the one at work in the Calvo-Drazen setting: First, it can favor either current or future consumption depending on the time path of devaluation probabilities. Calvo and Drazen deal instead with a tariff elimination of uncertain duration such that current observed prices (if the trade reform is in place) are always lower than expected future prices, and hence the intertemporal distortion always favors current consumption. Second, in our setting the value of the intertemporal distortion depends on the probability of policy reversal (since i_t while the peg is place depends on the probability of devaluation), while in Calvo-Drazen the tariff is always zero while the trade reform is in place.

The real effects we described in the previous paragraphs differ significantly from the effects at work in perfect-foresight models and stochastic models with complete insurance markets examined in the literature on exchange-rate-based stabilizations. In the perfect-foresight models, there is no interest differential between the domestic economy and the rest of the world while the currency remains pegged, and hence there are no distortions on relative prices within the fixed-exchange-rate period. In complete-markets models the valuation of wealth is not contingent on the state of nature, and thus the surge in seigniorage after a devaluation becomes a source of insurable, country-specific risk.

3.2 Rational Expectations Equilibrium

In order to define a rational expectations equilibrium, note that the time path of devaluation probabilities specified in (5) is endogenous and must be determined simultaneously with the equilibrium allocations and prices. Given a time path of devaluation probabilities between dates 0 and J, the model can be solved to yield particular paths for optimal state-contingent plans of the private sector. Taking the optimal plans for m and V, and the fiscal policy rules, one can compute the dynamics of reserves via equation (6). However, the given path of devaluation probabilities will only be consistent with a rational expectations equilibrium if the optimal plans that they support yield dynamics of reserves via (6) that produce an identical time path of devaluation probabilities when those dynamics of reserves are passed through (5).

A rational expectations equilibrium for this model consists therefore of intertemporal sequences of allocations and prices, and a time path of devaluation probabilities, satisfying the following conditions: (a) the optimality conditions of households and firms, (b) the market-clearing conditions for traded and nontraded goods, (c) the intertemporal government budget constraint, and (d) the consistency condition that equilibrium dynamics of reserves resulting from (6), for a given sequence of devaluation probabilities $Z \equiv \{z_0,...,z_{J-1}\}$, must produce the same sequence Z when used to compute the time path of devaluation probabilities via (5). This last condition ensures that, in equilibrium, the devaluation probabilities that reflect the central bank's policy reaction function are consistent with the rational expectations of currency collapse formulated by the private sector.

The nature of the policy experiment we posed implies that in the long run the equilibrium always converges to the stationary state of a deterministic setting with a constant rate of depreciation e^h. Hence, our experiment begins and ends in well-defined, deterministic stationary equilibria compatible with e^h. The steady-state equilibrium conditions that characterize this outcome, and the corresponding implicit connection between e^h and the stance of fiscal policy, can be illustrated clearly in a one-good version of the model in which labor supply is inelastic. In this case, the following conditions characterize a stationary equilibrium:

$$A\gamma\left(\frac{C/Y}{m/Y}\right)^{1+\gamma} = \frac{(1+e^h)(1+r^*)-1}{(1+e^h)(1+r^*)} \tag{10}$$

$$\frac{C}{Y} = 1 + r^*\left(\frac{R}{Y}+\frac{B}{Y}\right) - \frac{G}{Y} \tag{11}$$

$$\frac{G}{Y} = \left(\frac{m/Y}{C/Y}\right)\frac{C}{Y}\left(\frac{e^h}{1+e^h}\right) + \frac{C}{Y}\left[A\left(\frac{C/Y}{m/Y}\right)^{\gamma}\right] \tag{12}$$

$$(1-\alpha)A\left(\frac{K}{L}\right)^{-\alpha} = (r^*+\delta)h\big((1+e^h)(1+r^*)\big) \tag{13}$$

Notice that this system is expressed in terms of output shares to be consistent with the calibration exercise of Section 4. We also adopted from the next section the exponential transactions cost technology $S=AV^{\gamma}$.

The steady-state system (10)-(13) features the common problem of open economy models with standard preferences and trade in one-period bonds that the steady-state foreign asset position depends on initial conditions (see Mendoza and Tesar (1998)). Given an initial pre-stabilization asset position, and the fact that e^h is exogenous, it follows that in the pre-stabilization equilibrium (10)-(12) is a block-recursive three-equation system in the variables *(C/Y)*, *(m/Y)*, and *(G/Y)*, and (13) determines the steady-state capital-output ratio (and hence the level of output given the Cobb-Douglas technology). It also follows from (12) and the steady-state government budget constraint that in the pre-stabilization steady state transfers must be set to rebate the interest income on foreign reserves: $T=r^*R$. Note that, given the functional forms we chose, the steady-state output shares of reserves and foreign assets, and the value of e^h, there are generally unique solutions for the deterministic steady state system.[10]

The introduction of the peg sets the model's dynamics in motion since at $e=0$ the steady-state conditions will no longer hold. Every period during the peg there is some chance that the rate of depreciation is reset to e^h and the economy becomes deterministic. However, each date that this can happen the "initial conditions" of the corresponding deterministic post-collapse regime (i.e. the values of *B*, *R* and *K* at the date of collapse) would differ, and hence since the steady state depends on initial conditions, the deterministic long-run equilibrium to which the model converges from each possible date of collapse will generally differ. The fact that the same e^h is maintained across states of nature simplifies the analysis by ensuring that the long-run capital-output ratio and money velocity, as well as the steady-state levels of Y and K, are independent of the date of the currency collapse (as follows from (10) and(13)), but the stationary equilibria of consumption, real money balances, and government purchases will still vary depending on the overall net foreign asset position (i.e. $R+B$) to which the economy converges from each possible devaluation date. The same holds in the steady-state system of the richer model that incorporates the nontradables sector and the endogenous labor supply, with the caveat that in this case the steady-state output and capital stock would also depend on initial conditions.

3.3. Numerical Solution Method

The algorithm that solves the model extends the one we developed for a setting with exogenous devaluation probabilities in Mendoza and Uribe (1997) to the case in which these probabilities are endogenous. The algorithm of that paper can be thought of as a subprogram that yields equilibrium dynamics for a given *Z*.

We solve the model using the following iterative procedure:

(1) Fix the values of parameters for preferences, technology, the hazard rate function, the maximum duration of exchange-rate uncertainty, *J*, the post-collapse constant depreciation rate, e^h, the initial and critical reserve-to-GDP ratios, R_0/Y_0 and $(R/Y)^{crit}$, and the fiscal adjustment parameter κ.

(2) Start with a guess for the hazard function, Z^0, and use the subprogram from Mendoza and Uribe (1997) to compute equilibrium dynamics as if the hazard function were exogenous.

(3) Use the sequence of reserves-to-GDP ratios implied by step (2) to construct a new hazard function, Z^1, using equation (5). If this hazard function coincides with Z^0, then a rational expectations equilibrium has been found, else perform step (2) using Z^1 as the new guess.

The subprogram that computes equilibrium dynamics for a given *Z* takes advantage of the fact that at any date $t>0$ there are only two possible realizations of e_t: 0 or $e^h>0$. Since the state $e_t=e^h$ is absorbent, in each date macroeconomic aggregates can either: (a) follow the optimal state-contingent path corresponding to the state in which $e_t=0$; or (b) switch to the perfect-foresight path corresponding to the constant rate of depreciation e^h and the initial conditions pinned down by the values of the state variables on that date. The subprogram follows an iterative, backward-recursion strategy. Given *Z* and *J*, and an assumed post-collapse stationary equilibrium for the state variables K and B, the model features well-defined state-transition probabilities and terminal conditions, so that paths (a) and (b) can be solved by backward recursion. If these paths yield initial values for the state variables that are not the same as those compatible with the values set in the calibration, the terminal conditions are updated and the solution repeated until it converges (see the Appendix to Mendoza and Uribe (1997) for details).

Note that, while the maximum duration of the currency peg (J) is exogenous, this does not imply that the date of a speculative attack is necessarily exogenous. Nothing rules out a situation in which reserves reach the critical level before period J, triggering a speculative attack at a date that is endogenous to the model's dynamics. Similarly, the value of J can be set very high to examine the implications of a long horizon for currency risk.

4. Calibration and Numerical Simulations

4.1. Calibration

The model is calibrated to mimic some key aspects of Mexico's exchange-rate-based stabilization plan of 1987-94 following Mendoza and Uribe (1997).

a) Financial Sector: The transaction costs technology adopts the form $S(V_t)=AV_t^{\gamma}$, so that the equilibrium condition for accumulation of money balances implies an implicit money demand function $V_t=(i_t/1+i_t)^{1/(1+\gamma)}(\gamma A)^{-1/(1+\gamma)}$, where i is the nominal interest rate. This function is calibrated to M2 money demand in México, given strong empirical evidence in favor of a log-linear relationship between m and $i/1+i$.[11] The coefficient $-1/(1+\gamma)$ is the elasticity of money demand with respect to $i/(1+i)$, estimated at -0.15, so $\gamma=5.66$. The scale parameter A is set so that the high-inflation, pre-stabilization steady state mimics Mexico's M2/GDP ratio (31.8 percent on an annual basis) and nominal interest rate (177 percent annually) at end-1987. These two figures are inserted in the expression for equilibrium velocity $V_t=(i_t/1+i_t)^{1/(1+\gamma)}(\gamma A)^{-1/(1+\gamma)}$, and the expression is then solved for A (the result is $A=0.19$).

***b) Preferences and Technology**:* The risk aversion coefficient is set at $\sigma=5$, which is the lower-bound of the GMM estimates obtained for Mexico by Reinhart and Vegh (1995) using quarterly data for the period 1981-1991. Other preference and technology parameters are taken from the developing country model calibrated in Mendoza (1995) and are set as follows: $\rho=0.786$, $\omega=0.5$, $\mu=-0.218$ $\alpha T=0.42$, $\alpha N=0.34$ and $\delta=0.1$. $\varphi=0.06$ is set to mimic the standard deviation of Mexican investment using also Mendoza (1995). Finally, we assume $\beta=(1+r^*)^{-1}$ with r^* set at 6.5 percent per annum, which corresponds to the average real rate of return on equity in the U.S. in the period 1948-1981 reported by King, Plosser, and Rebelo (1988).

c) Balance of Payments and Fiscal Policy: The initial and critical values of the ratio of foreign reserves to gross domestic product are calibrated to mimic, respectively, the values observed at the beginning and at the end of the Mexican stabilization plan. The initial ratio (which uses gross reserves as of end-February 1988, when the exchange rate was initially fixed) was 7.1 percent in annual terms. The final ratio, which uses gross reserves in November, 1994, was 2.8 percent also in annual terms. Notice that this final ratio corresponds to reserves in the period just before the devaluation. The pre-stabilization and post-collapse depreciation rates are both set to e^h=27 percent at a quarterly frequency, to reflect Mexico's inflation rate at the end of 1987 (which was 160 percent on a twelve-month basis). We also set J=24 to reflect the fact that Mexico has suffered currency collapses at the end of the six-year presidential terms in 1976, 1982 and 1994.

Given the above parameter values and functional forms, a system analogous to (10)-(13), expanded to re-introduce nontraded goods and endogenous labor supply, is used to solve for the pre-stabilization steady-state. The solution includes the pre-stabilization steady-state values of seigniorage and transactions cost revenue, government purchases and transfers, so that the pre-stabilization amount of government outlays ($G_{-1}+T_{-1}$) can be determined.

The parameter κ, which measures the magnitude of fiscal adjustment during the peg as a fraction of ($G_{-1}+T_{-1}$), is calibrated by requiring that the reserve-to-GDP ratio (R/Y) hits its critical level at date *J*-2 if the peg is in place at that point. Thus, we adopt the view that in the benchmark case, agents in period *J*-1 expect a peg that has survived until then to collapse in period *J* with probability 1 both because *J* is the assumed maximum duration of the program and because reserves just hit their critical level one period earlier.[12] The implied value of κ is 0.133, which means that when the stabilization program is announced the government tightens fiscal policy sharply to reduce total outlays by 87.7 percent.

Determining the value of κ that satisfies the above conditions requires a slight extension of the solution method. In particular, we use the following iterative procedure:

(1) Start with an initial guess, Z^0.

(2) Obtain a rational expectations equilibrium given Z^0 using the subprogram described in Mendoza and Uribe (1997).

(3) Compute κ^0 as the solution to the difference equation $R_{t+1} = (1+r^*)R_t+SR_t+TC_t-\kappa^0(T_{-1}+G_{-1})$, with initial condition $R_0=(R_0/Y_0)Y_0$ and terminal condition $R_{J-2}=(R/Y)^{crit}Y_{J-2}$, where SR_t and TC_t are short for seignorage revenue and transaction costs, respectively. This equation results from combining equations (7) and (8). The solution takes the form:[13]

$$\kappa^0 = r^* \left[\frac{\left(\frac{R_0}{Y_0}\right) Y_0 (1 + r^*)^{J-2} + \sum_{j=0}^{J-3} (1 + r^*)^{J-3-j} \left(SR_j + TC_j - \left(\frac{R}{Y}\right)^{crit} Y_{J-2} \right)}{(G_{-1} + T_{-1})\left((1 + r^*)^{J-2} - 1\right)} \right] \quad \textbf{(14)}$$

Note that all the terms on the right-hand-side of (14) are provided either in step (2) or by the solution of the pre-stabilization steady-state. Once κ^0 has been obtained, a series for foreign reserves can be constructed using the above difference equation.

(4) Construct a new hazard function, Z^1, by passing the time path of reserves from step (3) through equation (5). If Z^1 equals Z^0, then a rational expectations equilibrium has been found; otherwise, perform steps (2) and (3) using Z^1 as the guess. Continue this procedure until the hazard function converges. The value of κ resulting from step (3) in the last iteration is the one used in the benchmark calibration of the model.

d) Parameters of the Hazard Rate Function

We parameterize the hazard rate function starting from the premise that the model ought to mimic devaluation probabilities that have been estimated in the empirical literature. Recent empirical evidence yields one robust prediction in this regard: devaluation probabilities under fixed-exchange-rate regimes evolve as J-shaped curves over time. The devaluation probability is decreasing after a peg is introduced, and eventually becomes increasing and higher than when the peg started.

Ample evidence in favor of J-shaped devaluation probabilities has been found both in country-specific studies based on models of speculative attacks as well as in cross-country studies of the determinants of exchange-rate vulnerability. For example, Blanco and Garber

(1986) estimated devaluation probabilities for the Mexican peso in the six years before the devaluations of 1976 and 1982 based on a Krugman-style model of balance-of-payment crises and an econometric model of Mexican money demand. These authors estimated a probability of collapse of 0.2 early in 1977, declining to near zero in about a year, rising slowly in 1978-79, and rising rapidly to about 0.3 before the collapse. These results are qualitatively consistent with the findings of Goldberg (1994) who also studied Mexico but extended the sample to include the 1980-86 period. Klein and Marion (1997) use a logit method to identify factors that influence the duration of currency pegs in a panel of monthly data for 17 countries over the 1957-91 period. They find strong evidence showing that sharp real appreciations and losses of foreign reserves predate devaluations and that devaluation probabilities are J-shaped. Probabilities of collapse one month before a devaluation are as high as 0.89, with 1/10 of the estimates higher than 0.55. Frankel and Rose (1996) and Kaminsky and Reinhart (1999) provide further support for the finding that real appreciation and reserve losses are key predictors of currency crises.

In view of the fact that most of the empirical literature (except Klein and Marion) does not yield direct estimates of the parameters of hazard rate functions like (5), we opted for setting the values of these parameters following a "curve-fitting" procedure: First, we set a smooth J curve to represent a "target" hazard function consistent with the empirical evidence of J-shaped devaluation probabilities -- this target function is the same exogenous hazard rate function used in Mendoza and Uribe (1997), which featured an initial devaluation probability at about 0.4, falling to zero in about 12 quarters and raising to 0.8 prior to the collapse. Second: we set the algorithm that solves the equilibrium of the model to search for values of B and Γ that yield the closest approximation, in the Euclidean sense, to the target hazard rate function. This approach yields the following parameter structure: Β=0.17 and Γ=-2.9. Note that this procedure does not impose any specific restrictions on the two parameters. Still, the solution yields Β>0, which is consistent with the view that the probability of devaluation increases as reserves fall. The value of Γ reflects the initial odds of a devaluation at the time the currency peg is introduced, given the initial gap between observed lagged reserves and their critical level.

4.2. Benchmark Simulation and Mexico's Stylized Facts

The solutions for state-contingent macroeconomic dynamics and the endogenous devaluation probabilities produced by the benchmark calibration are plotted in Figure 1. The equilibrium dynamics plotted in this figure correspond to state-contingent allocations measured as percent deviations from the deterministic pre-stabilization steady state. The continuous lines represent the dynamic equilibrium paths in the event that the currency peg continues, and the dotted lines indicate the allocations to which the variables shift on impact when a devaluation occurs.

Since the model was calibrated to capture roughly the policy stance of Mexico's 1987-1994 exchange-rate-based stabilization, it is instructive to review briefly the cyclical dynamics of the Mexican economy during that period following the discussion in Mendoza and Uribe (1997). From the first quarter of 1988 to the last quarter of 1994, Mexico's real exchange rate appreciated by 35.4 percent -- the Mexican plan was announced in December of 1987 but the exchange rate was fixed two months later. The deviations from trend in GDP, investment, GDP, and private consumption widened considerably during 1988-92, but in 1993 all three fell below trend, in line with the common feature of exchange-rate-based stabilizations that recessions often predate currency collapses. The fluctuations in real variables were also very large. At the peak of the cycle in 1992, the deviations from trend in GDP and consumption were about 6 percentage points higher, and the one for investment was 15 percentage points higher, than at the cyclical minimum reached just before the beginning of the program in early 1987. The boom in private consumption and the appreciation of the real exchange rate were nearly perfectly positively correlated until 1993, when consumption began to slow down but the real appreciation continued. Mexico's external imbalances worsened at a steady rate until the current account deficit reached 8 percent of GDP just before the devaluation at the end of 1994.

The results of the benchmark simulation show that the model is roughly consistent with these stylized facts. In particular, the model recreates boom-recession cycles in GDP, consumption, and investment with recessions that pre-date the devaluations. Aggregate and sectoral consumption move together with the real exchange rate for most of the duration of the stabilization plan, suggesting that the model can explain the high correlation between the real exchange rate and consumption that lies behind the price consumption puzzle. The trade balance worsens markedly on the early stages of the peg, and then remains stable until it improves in a sudden jump that coincides with the collapse of the currency.

The endogenous monetary dynamics of the model are in line with the predictions typical of a model of balance-of-payments crises. Central bank foreign reserves increase initially, as the decline in the velocity of circulation that occurs in the early stages of the peg reflects the re-monetization of the economy in response to the reduction in the nominal interest rate and the boom in real economic activity.[14] This re-monetization plays a key role in allowing the model to mimic the initial declining path observed in empirical estimates of devaluation probabilities. After this initial stage, reserves decline gradually and then rapidly until they are finally depleted in a sudden jump to their critical level just before the collapse of the peg. This pattern in turn produces an endogenous time path of devaluation probabilities that, after the initial declining stage, begins to increase gradually and then rapidly, thus approximating the J shape of devaluation probabilities identified in empirical research.

The model does share an important empirical drawback of most existing models of balance-of-payments crises in that it requires a collapse of money balances at the time of the currency crash. Mexico's monetary aggregates did not collapse as the December, 1994 devaluation took place. This resilience of the quantity of money followed several months of massive sterilized intervention by the central bank and large-scale swapping of public debt from peso-denominated public bonds to dollar-linked bonds (see Calvo and Mendoza (1996)). In line with this evidence, some recent studies have examined models in which a balance of payments crisis may occur without a collapse in the demand for money (see Kumhoff (1999)).

In comparing the model's predictions to Mexican data, we acknowledge that Mexico's business cycles are caused by several factors in addition to the distortions resulting from currency risk, which is the only driving force of business cycles in the model we proposed. In Mendoza and Uribe (1997) we addressed this issue by trying to isolate the potential contribution of exchange-rate uncertainty from the effects of other sources of business cycles using a VAR model proposed by Calvo and Mendoza (1996). We used the interest-rate differential between Mexican and U.S. treasury bills as a measure of the probability of devaluation and default, and found that this differential explains about 40 percent of the variability of macroeconomic aggregates and the real exchange rate over 24 quarters.[15] Taking into account the total magnitude of the observed fluctuations, this suggests that an ideal simulation of our model should not be able to account for more than an 18 percent real appreciation, consumption and GDP booms in excess of 2 percent, and investment booms in excess of 5 percent. Hence, the 14 percent real appreciation produced by this model is less than 1/2 the full real appreciation observed in México during 1988-94, but is close to the 18 percent appreciation measured using the VAR.

We also acknowledge that in our effort to follow Mundell's analysis, we specified a functional form for the central bank's reaction function that may be too restrictive in the light of existing empirical evidence. Klein and Marion (1997), Frankel and Rose (1996) and Kaminsky and Reinhart (1999) all show that the appreciation of the real exchange rate is a robust predictor of the collapse of fixed exchange rates even when the information provided by foreign reserves is taken into account. Moreover, Klein and Marion show that even if both reserves and the real exchange rate are used as predictors, the duration of the peg per se is also a robust predictor of currency crashes. In line with this finding, we found that simulations of the model in which a linear term in t is introduced into the functional form of z_t produce a closer fit to the J-curves estimated in the data than the basic specification set in equation (5). Thus, we did not expect our basic specification to mimic closely the Mexican data, but were still surprised by its ability to approximate some of their key features.

4.3 Policy Determinants of Currency Crashes: Revisiting Mundell’s Findings

The last set of numerical exercises examines the implications of altering the responsiveness of the policy reaction function to observed changes in reserves (i.e. altering the value of B) with the aim of exploring the predictions of the model for an experiment analogous to the one conducted by Mundell (1960). We conduct this analysis in two stages. First, we simulate the model under alternative values of B, keeping the values of all other parameters constant, and compare the results to those of the benchmark model. Second, we allow Β to vary as in the first case, but we also allow fiscal policy to vary so as to "put up a fight" for the central bank's foreign reserves. This is done by computing for each value of Β the fiscal adjustment (i.e. the required changed in κ) that is necessary for the currency peg to have a chance to continue to last a maximum of *J* periods -- the same as is the benchmark case.

The first experiment, in which Β is changed while maintaining unaltered the rest of the structure of the model, sheds some light on the model's predictions regarding the occurrence of endogenous speculative attacks that lead to a currency collapse before date *J*. Figure 2 plots the hazard function, the reserves-to-GDP ratio, GDP, and the real exchange rate for the benchmark case and for cases in which the value of Β is 10, 20 and 40 percent larger than in the benchmark parameterization. The horizontal dotted lines in the plots of the reserves-to-GDP ratio indicate the values of R_0/Y_0 and $(R/Y)^{crit}$, both of which are constant across the simulations.

The plots in Figure 2 show that as the speculative capital outflows indirectly captured in Β strengthen, the same stance of fiscal and exchange rate policies results in currency collapses that occur sooner than in the benchmark case. This is the case despite the fact that the domestic nominal interest rate will also increase more and faster than in the benchmark case (as implied by the interest parity condition implicit in equation (9)). When Β is 40 percent higher than in the benchmark case (panel d), the devaluation probability remains very high throughout the duration of the peg, and the peg itself cannot last more than 4 quarters. Foreign reserves decline very rapidly and the cyclical increases in real output and the real exchange rate are smaller than in the benchmark simulation. Naturally, the opposite results would obtain if we tried reducing Β instead of increasing it -- as speculation becomes weaker, the same stance of fiscal policy would result in currency pegs that could be maintained for more than *J* periods (if we relaxed the assumption that at *J* the currency must collapse with probability 1).

A higher value of B brings forward the date of a speculative attack in part simply because changing this exogenous parameter implies a higher probability for the collapse of the currency for any given fall in the reserves-to-GDP ratio. There is in addition an endogenous channel that accelerates the collapse by altering the dynamics of reserves. As z_t rises, the premium on the domestic interest rate rises, the velocity of circulation of money rises and the demand for money falls, thereby altering the time path of reserves. The plots in Figure 2 show that, as a result, an increase in B leads to a smaller initial surge in reserves -- or even no increase at all as in the case of panel (d) -- and a more rapid depletion of reserves after the initial surge.

The results for the second experiment, where B and κ are allowed to vary, are plotted in Figure 3. Note that κ is falling in each case so that larger cuts in government outlays during the stabilization plan ensure that the ratio of reserves to GDP does not reach the critical level until the same date as in the benchmark scenario. Clearly, this response of the government neutralizes the effects of modest variations in B and yields results roughly similar to the benchmark case. However, if B is too large (as in panel (d)), the logistic functional form of z_t produces probabilities of devaluation that are virtually equal to 1 despite the dynamics of reserves. Hence, even tough foreign reserves reach the critical level at $t=J-1$, the results are similar to the case in which government policy is not tightened and reserves reach the critical level much earlier.

Figures 2 and 3 can now be examined jointly to study the implications of an experiment similar to the one in Mundell (1960), in which the government tightens policy in an effort to defend the peg as speculation grows stronger. There is a nontrivial difference because Mundell focused on the case in which this is done by the central bank adopting measures to increase the nominal interest rate under conditions of imperfect capital mobility. This is ruled out by the assumption of perfect capital mobility in our model, and hence we consider instead the adjustment to fiscal policy as the closest approximation. As mentioned in the introduction, Mundell showed that macroeconomic dynamics would vary widely depending on the particular static parameters that measured the "speeds of response" of speculators and policy-makers, and that dynamics could turn from stable to unstable, or from cyclical to asymptotic.

Comparing Figures 2 and 3, we find that in our model, just like in Mundell's, the relative responses of speculative capital outflows and fiscal policy tightening are critical for determining macroeconomic dynamics. These figures represent two extreme cases of the government's response. Figure 2 illustrates cases in which the government does not respond and simply keeps κ at the benchmark level of 13.3 percent, while Figure 3 reports cases in which the government responds fully and hence reduces κ to protect its foreign reserves. Comparing panels (b) and (c) of the two figures we note that the cyclical dynamics of GDP and the real appreciation differ sharply between these two extreme cases. While none of these experiments show the oscillatory dynamics that Mundell argued could exist for some combinations of speed-of-response parameters, we did find other rare examples in which equilibrium dynamics could display oscillations (for instance in the case in which Γ=0, B=-0.17 and κ=0.234). Hence, we conclude that Mundell's findings are roughly consistent with the quantitative predictions of our model.

5. Conclusion

This paper re-examined Mundell's (1960) model of balance-of-payments crises in the light of modern international macroeconomics. In particular, the paper derived the quantitative predictions of an intertemporal, general equilibrium model in which the probability of devaluation is endogenous and depends on the observed evolution of foreign reserves. The model represents a two-sector small open economy with perfect capital mobility, but with incomplete contingent-claims markets. In this model, exchange-rate uncertainty introduces a time-variant premium on the domestic interest rate that induces stochastic distortions affecting the relative prices determining saving, investment and the supply of labor. In addition, market incompleteness implies that these distortions also introduce state-contingent wealth effects resulting from the unproductive use of government revenue and suboptimal investment decisions.

The economic fluctuations that result from the distortions on relative prices and wealth reproduce some basic features of exchange-rate-based stabilizations. In particular, the model is consistent with large real appreciations, large external deficits, booms in output and absorption followed by recessions that predate currency collapses, and a high positive correlation between the real exchange rate and domestic absorption for the duration of currency pegs. The model is also relatively successful in producing endogenous devaluation probabilities that capture the J-shaped nature of devaluation probabilities that have been identified in actual data. These results also imply that the model can be useful for providing an economic interpretation to the findings of several recent studies that identify foreign reserves, and other key macroeconomic variables, as robust predictors of currency crashes.

Our analysis suggests that, for a given policy setting, endogenous speculative attacks occur earlier in economies where devaluation probabilities are more sensitive to observed changes in foreign reserves. This is in part because in such a case investors simply grow more anxious about the sustainability of a currency peg for a given change in reserves, but also because in equilibrium their increased sensitiveness results in a higher premium on the domestic interest rate that magnifies the distortions of the model and accelerates the depletion of reserves. The simulations also produce results consistent with Mundell's (1960) analysis of speculators and policy-makers engaged in a "fight" over foreign reserves. Mundell showed that, depending on the sensitiveness of investors to changes in reserves relative to the policy response of the government, the dynamics of adjustment could be stable or unstable, oscillatory or asymptotic. In our model equilibrium dynamics are also very sensitive to increases in the sensitiveness of speculators that are matched by a tightening of fiscal policy intended to protect foreign reserves.

The policy lessons that can be drawn from this exercise are interesting. First, we note that in this model losses of foreign reserves, real appreciation and external deficits are *not* exogenous triggers of balance-of-payments crises. What lies behind these crises is the lack of confidence of the private sector, which is implicitly modeled here via a central bank policy reaction function that sets the probability of devaluation as a decreasing function of the stock of foreign reserves. Second, the cyclical dynamics of exchange-rate-based stabilizations and the collapse of fixed exchange rates do not need to result from sudden changes in fiscal or monetary policies. We showed that a model calibrated to reflect Mexico's tight and sustained policies between 1987 and 1993 still yields large real appreciation and large trade deficits, and that the currency crises may occur sooner or later depending on the stance of fiscal policy and the sensitiveness of speculative capital outflows to observed changes in foreign reserves. Third, since crises in our model can be produced by lack of confidence and confidence is linked to foreign reserves, Mundell's (1960) key policy recommendation remains valid today: "an effective system of international payments based on fixed exchange rates must be one which provides a reasonably high degree of international liquidity" (p. 246). As Calvo and Mendoza (1996) noted, however, this "reasonable high degree of international liquidity" can be a very large figure in today's global economy.

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Notes

1. It is worth noting that Mundell's (1960) setup assumed flexible prices, in contrast with the sticky-price assumption of the classic Mundell-Fleming model. Mundell noted that price stickiness was not required by the arguments of his 1960 article.

2.Mendoza and Uribe (1997) examined a model with this feature, but taking devaluation probabilities as exogenous and ignoring foreign reserves, so currency collapse is also exogenous.

3.Models in this class include perfect-foresight models with time-separable preferences and no borrowing constraints. Some models that can resolve the puzzle have been developed recently by using preferences displaying habit formation (Uribe 1998a)) or by introducing uncertainty regarding the duration of the peg (Mendoza and Uribe, 1997).

4.We show in Mendoza and Uribe (1997) that this assumption could be changed with little effect on the numerical results for the assumption that at J there is a devaluation with positive probability, and after that date there is no currency uncertainty.

5.Note that this framework can be easily extended to condition z_t on other key predictors of currency collapses identified in the recent empirical literature such as the real exchange rate. Uribe (1998b) shows that real exchange targeting, i.e., exchange rate policies whereby the rate of depreciation is set as an increasing function of the relative price of nontradables in terms of tradables, can produce endogenous aggregate instability.

6. The term $m_tV_tS(V_t)$ in (6) can be interpreted as profits of government-owned banks. However, since they will be used only for unproductive government purchases, we could also assume that transaction costs are simply a deadweight loss.

7.Mendoza and Uribe (1997) showed that a model in which seigniorage and transaction costs are rebated to households as lump-sum transfers fails to account for key features of the data. Moreover, the analytical work of Calvo and Drazen (1993) and Helpman and Razin (1987), as well as our review of Mexican fiscal policy during the 1987-94 exchange-rate-based stabilization (which is the benchmark for the calibration of the model) suggest that the case without rebates is perhaps more realistic.

8. Three other important differences between our model and Calvo's are: (a) in Calvo's model government outlays are only lump-sum transfers, which rules out the fiscal-induced wealth effects of our model, (b) in Calvo's model money velocity is constant while in our model it is a decreasing function of the nominal interest rate, and (c) our model allows for changes in the depreciation rate to affect labor supply and capital accumulation, while in Calvo's endowment-economy model these changes can only affect consumption.

9.Note that this key difference between the two approaches would still be present even if we altered our model to bring it closer to Calvo's by considering an endowment economy in which seigniorage and transaction cost revenue are fully rebated to households.

10.Calvo (1987) suggested that there is a risk of obtaining multiple solutions for long-run monetary equilibria using interest-elastic money demand. However, we have ample numerical evidence showing that this is generally not the case with the functional form $S=AV^{\gamma}$.

11.See Calvo and Mendoza (1996) and Kamin and Rogers (1996).

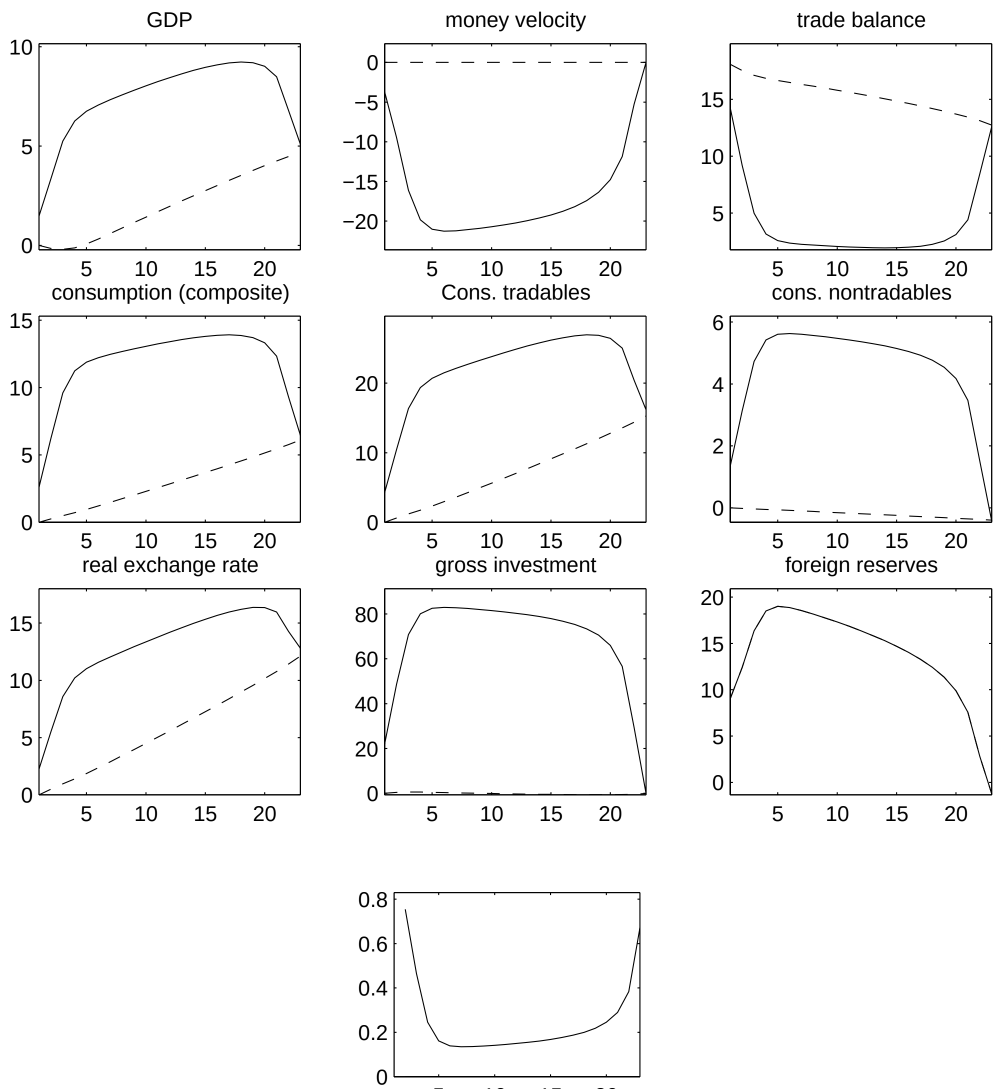
12.We show in the simulation results that under alternative parameter configurations, particularly as κ and B change, the peg may endogenously terminate before period J.

13.Note that the necessary fiscal adjustment is higher (i.e., κ^{0} is smaller) the higher the pre-stabilization level of government outlays, the higher the critical level of foreign reserves, the lower the initial level of reserves, and the lower the level seignorage revenue and transaction costs.

14. Typically, models of currency crises do not focus on this initial build up of reserves because they start from an existing fixed exchange rate, while our policy experiment starts with a switch from a floating exchange rate to a fixed exchange rate.

15.Note, however, that the interest differential is almost perfectly correlated with the Mexican interest rate, and the latter was influenced by sterilized intervention of large capital flows during 1990-94. Thus, the differential is at best a noisy measure of the "market" expectations of the sustainability of the peg.

Figure 1: MACROECONOMIC DYNAMICS OF AN EXCHANGE-RATE-BASED STABILIZATION OF UNCERTAIN DURATION WITH ENDOGENOUS HAZARD FUNCTION*



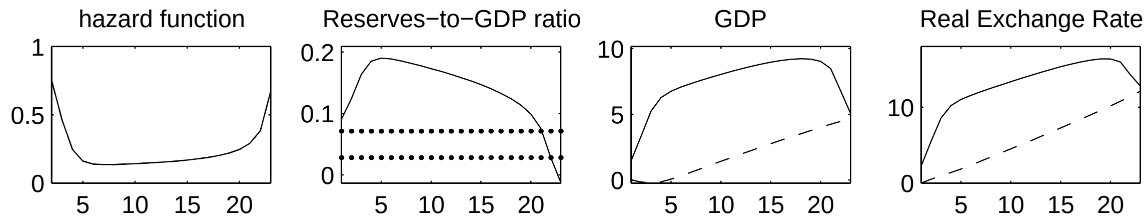
hazard function

* All variables, except NX_t/Y_t, are expressed in percentage deviations from their pre-stabilization steady-state. Solid lines denote pre-collapse values and broken lines at-collapse values. The hazard function takes the form $z_t \equiv Pr(e_{t+1} = e^h | e_t = 0) = exp(w_t)/(1 + exp(w_t))$, where $w_t = \Gamma + B/(\frac{R^L_{t-1}}{4Y^L_{t-1}} - (\frac{R^L_{t-1}}{4Y^L_{t-1}})^{crit})$, with $B = .17$ and $\Gamma = -2.9$.

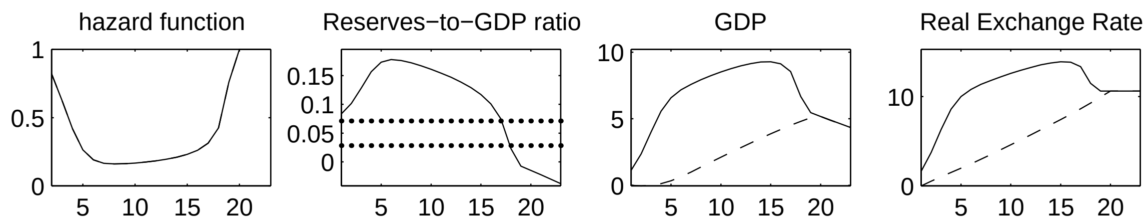
Figure 2

Sensitivity analysis: Varying the sensitivity of the hazard function to changes in foreign reseves

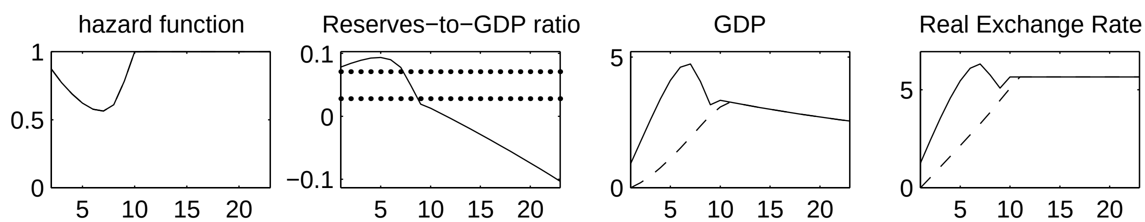
(a) Benchmark parameterization: $B = 0.17$, $\Gamma = -2.93$



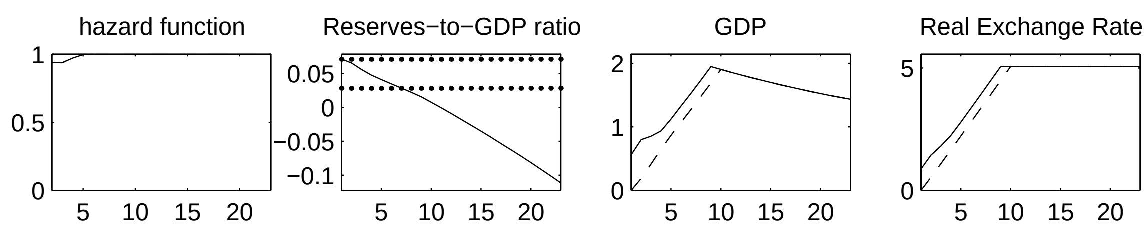
(b) $B = 1.1 \cdot B^{benchmark}$



(c) $B = 1.2 \cdot B^{benchmark}$



(d) $B = 1.4 \cdot B^{benchmark}$

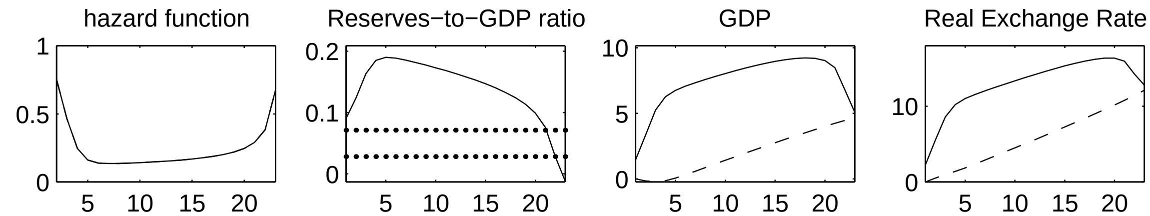


Note: The dotted lines on the second column denote the initial and critical reserve-to-GDP ratios (R_0/Y_0 and $(R/Y)^{crit} < R_0/Y_0$). The solid lines on the second and third columns show pre-collapse values and the broken lines show values at the date of collapse. GDP and the real exchange rate are measured in percentage deviations from their respective pre-stabilization steady states.

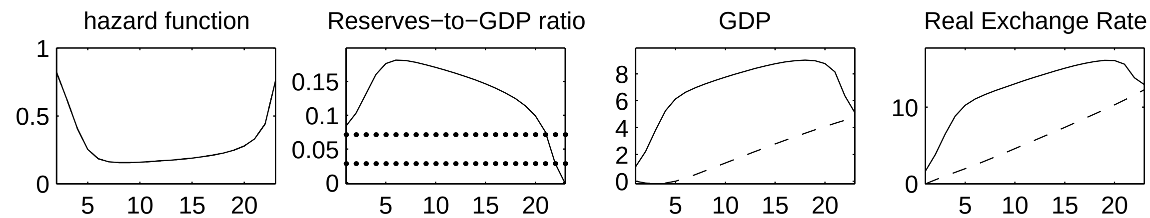
Figure 3

Sensitivity analysis: Varying the sensitivity of the hazard function to changes in foreign reseves (B) and the degree of fiscal adjustment (κ)

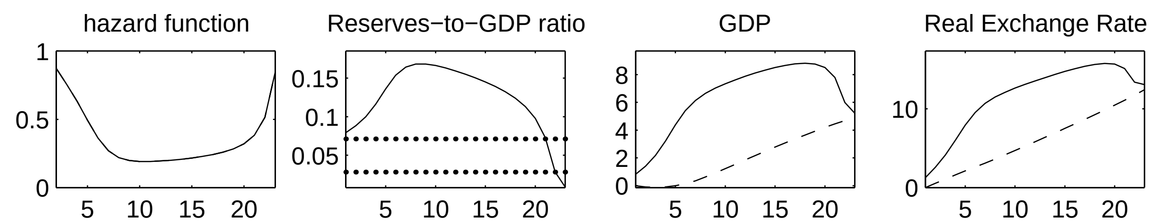
(a) Benchmark parameterization: $B = 0.17$, $\Gamma = -2.93$, and $\kappa = 0.13$



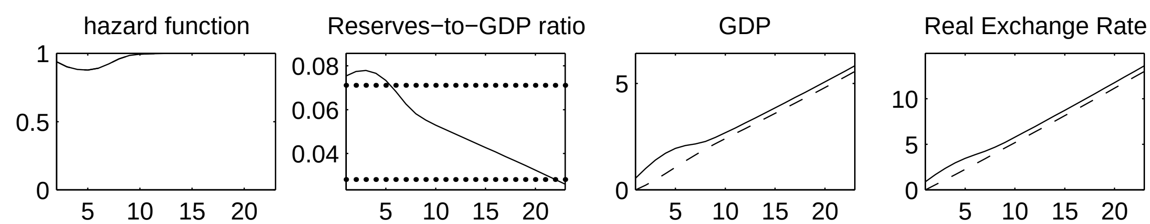
(b) $B = 1.1 \cdot B^{benchmark}$, $\Gamma = -2.93$, and $\kappa = 0.12$



(c) $B = 1.2 \cdot B^{benchmark}$, $\Gamma = -2.93$, and $\kappa = 0.11$



(d) $B = 1.4 \cdot B^{benchmark}$, $\Gamma = -2.93$, and $\kappa = 0.07$



Note: In each row, the adjustment in the parameter κ guarantees that if the program survives until period $J - 2$, then the reserves-to-GDP ratio reaches its critical value of 2.8 percent at that date. The dotted lines on the second column denote the initial and critical reserve-to-GDP ratios (R_0/Y_0 and $(R/Y)^{crit} < R_0/Y_0$). The solid lines on the second and third columns show pre-collapse values and the broken lines show values at the date of collapse. GDP and the real exchange rate are measured in percentage deviations from their respective pre-stabilization steady states.