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An Interest Rate Defense of a Fixed Exchange Rate?

by

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Abstract

Defending a government's exchange-rate commitment with active interest rate policy is not an option in the well-known Krugman-Flood-Garber (KFG) model of speculative attacks. In that model, the interest rate is the passive reflection of currency-depreciation expectations. In this paper we show how to adapt the KFG model to allow for an interest rate defense. It is shown that increasing domestic-currency interest rate makes domestic assets more attractive according to an asset substitution effect, but weakens the domestic currency by increasing the government's fiscal liabilities. As a result raising the interest rate hastens the speculative attack when speculation is motivated by underlying fiscal fragility.

1. Introduction and Literature Survey

This paper is about the possibility of an active interest-rate defense in the Krugman-Flood-Garber (KFG) model of speculative attacks.[1] It is straightforward to see that this requires a departure from uncovered interest parity (UIP), which was a basic KFG building block. UIP implies that the domestic-currency interest rate is the *passive* reflection of devaluation expectations. There is, therefore, no room for *active* interest rate policy.

A policy-responsive wedge must be driven into the interest parity condition. Readers are used to risk aversion implying such a wedge and this is one *entrée* to the problem. A good bit of progress on interest rate policy is possible, however, in an environment of certainty so we will forgo uncertainty for now.[2] We bring in our wedge by *assuming* domestic and foreign bonds to be imperfect substitutes in a convenient way that allows the domestic monetary authorities room to maneuver in setting the interest rate. This defines the program of the paper: solving a generalized version of the KFG model in which domestic and foreign bonds are imperfect substitutes and the domestic-currency interest rate is one of the variables controlled by domestic monetary policy.

Our goal is to find the scope for policy tradeoffs involving a number of potential policy tools— interest rates, nominal-liability growth (money and bonds), the real government deficit and international reserve management all as they arise in the KFG model. We evaluate policies—on an equal footing—in terms of how long the policies preserve a given fixed exchange rate. This analysis is supported by numerical simulations parameterized with data from Mexico in the 1990s. We also apply the model in a heuristic way to the East Asian crises of the late 1990s.

There have been policy debates recently over the efficacy of defending exchange rates using the interest rate, and they have spurred a literature that is closely related to the present paper.[3] At the empirical level, Furman and Stiglitz (1998) find, in a small set of episodes of crises in nine emerging markets, that interest rate hikes are associated with exchange rate depreciations. Kraay (1999), considering a larger sample of speculative attacks in developed and developing economies, concludes to a lack of systematic correlation between interest rates and the outcome of speculative attacks. Goldfajn and Baig (1998) do not find any robust correlation between interest rates and exchange rates in the recent crises in Southeast Asia.

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[1] See Krugman (1979) and Flood and Garber (1984b).

[2] Krugman (1979) was conducted in certainty as was the first section of Flood and Garber (1984b).

[3] See Lane *et al* (1999), chapter 6, for a review of this nascent literature.

Overall, the evidence presented in these papers is difficult to interpret as a systematic lack of efficacy of interest rate defenses, given the obvious reverse causality and endogeneity problems, but at least suggests that the link between the level of interest rates and the credibility of the currency is not systematic and depends on the circumstances. Thus theoretical work may be useful in identifying the circumstances in which an interest rate defense can work and those in which it does not.

Recent theoretical papers studying the efficacy of interest rate defenses of fixed currency pegs include Bensaid and Jeanne (1997), Drazen (1999) and Lahiri and Végh (1999). The first two papers belong to the "second generation" or "escape clause" approach to currency crises. Bensaid and Jeanne's (1997) paper was motivated by the 1992-3 crisis of the European Monetary System; it formalizes the point that raising the interest rate may be a self-defeating strategy because of the harm it inflicts on the economy, and can make speculation against the currency self-fulfilling. Drazen (1999) presents a framework in which the government chooses between two defense strategies, raising the interest rate or borrowing reserves. One important aspect of this decision—in Drazen's setup—is that it signals to the market some unobservable characteristics of the government, such as the availability of reserves or the government's resolve to defend the currency. Drazen shows that depending on the precise informational structure, raising the interest rate might or not send a good signal and enhance the credibility of the fixed peg.

The present paper is more closely related to Lahiri and Végh (1999), who, like us, adopt a KFG-type framework and stress the fiscal implications of an interest rate defense. Lahiri and Végh find that the link between the level of interest rates and the timing of the attack is non-monotonic: an interest rate rise might delay the attack if it is small, but hasten it if it is large. This stems in part from the menu of assets available to households in their model: they introduce a new asset, "liquid bonds", which, on the one hand is assumed to be part of broad money together with cash holdings, but on the other hand pays interest—though not the same as regular bonds. Thus an interest rate defense (defined as a rise in the interest rate on liquid bonds) increases money demand, which contributes to delay the attacks. Like in our model, this also increases fiscal liabilities, with an opposite effect. Because money demand has been kept standard in our model only the second effect is present.

2. The Model

We study a small open economy in continuous time. There is one homogeneous global good and the Law of One Price applies at all times, making the domestic price level equal to exchange rate (the foreign price level is constant and normalized to 1).

The first group of equations is almost the same as in KFG. These are the equations for money demand, interest rate parity, the central bank balance sheet, and the reserves constraint.

$$\frac{M_t}{S_t} = \mu \exp(-\alpha r_t) \qquad (1)$$

$$r_t = r^* + \frac{\dot{S}_t}{S_t} + \theta \frac{B_t}{S_t} \qquad (2)$$

$$M_t = D_t + S_t \, R_t^* \qquad (3)$$

$$R_t^* \geq 0 \qquad (4)$$

In levels, M is domestic-currency high power money; S is the exchange rate defined as the domestic-currency price of foreign exchange; r is the domestic-currency interest rate and r^* is the foreign-currency analog (assumed to be constant); B is world-wide private holding of domestic-government domestic-currency debt; D is domestic credit (bonds) held by the domestic central bank, and R^* is domestic central bank holding of foreign currency debt.

The only difference from KFG is the term $\theta B / S$ in the interest parity condition. This term captures the idea that domestic and foreign bonds are imperfect substitutes. It is positive (by assumption) and increasing with the quantity of domestic bonds in international investors' portfolios.[4] KFG is obtained for $\theta = 0$. Then, the equilibrium is pinned down by the specification of an exogenous path for domestic credit, D. This is no longer true if $\theta > 0$ because there is nothing in equations (1)-(4) to determine supplies and demands for domestic bonds.

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[4] Our justification for a wedge in UIP is the assumption that domestic and foreign–currency bonds are imperfect substitutes in agents' portfolios. At a deeper level, imperfect substitution may reflect a utility-based bias toward domestic currency assets that could be derived from domestic-currency assets having a *liquidity* advantage over foreign currency assets (see Lahiri and Végh, 1999). The wedge could equally well result from increasing marginal domestic-currency borrowing cost (see Drazen, 1999). The function we use here is derived in uncertain environment in Jeanne and Rose (1999). In the first version of this paper we used a formulation, derived from Flood and Marion (2000), where the wedge was proportional to the ratio of domestic bonds to foreign bonds in investors' portfolio—and we obtained similar results.

We close the expanded model by introducing a more fully specified domestic government's budget constraint, and one other accounting identity.

$$\dot{N}_t = r_t(N_t - D_t) - r^* S_t R_t^* - S_t \tau \qquad (5)$$

$$N_t = B_t + D_t \qquad (6)$$

The government's budget constraint (consolidated) determines the evolution of the total stock of outstanding domestic nominal bonds, N. According to equation (5), N grows in pace with the government's net deficit; $r(N - D)$ gives net interest payments of the consolidated government; interest payments to the domestic government on international reserve holding are $r^* S R^*$, and the real level of taxes is τ, which may be either positive or negative. Throughout the paper we take τ as exogenous and constant. In equation (6) all domestic government bonds must be held either by the world private sector or by the domestic monetary authority.

In all of our work, the monetary authority fixes the exchange rate at $\bar{S}$ as long as international reserves are above an exogenous lower bound, set at zero in our analytical work. When reserves are exhausted the exchange rate floats. The survival of the fixed-rate regime depends on the behavior of the post-collapse floating exchange rate. *Let $\tilde{S}$ be the shadow exchange rate, which is defined to be the flexible exchange rate that would prevail if the fixed rate regime were attacked successfully.* As usual, the fixed-rate regime survives until attack is worthwhile to speculators, i.e., $\tilde{S} \geq \bar{S}$. In the current perfect foresight setting, an anticipated attack takes place when $\tilde{S} = \bar{S}$.

KFG relies on the assumption that domestic credit grows at the same rate, *g, before* and *after* the collapse, and does not jump at the time of the collapse. If $\theta=0$, the collapse time T is simply the solution to the standard formula:

$$\frac{D_0 \exp(gT)}{\bar{S}} = \mu \exp(-\alpha(r^* + g)), \qquad (7)$$

implying that increasing the growth rate in domestic credit hastens the collapse of the fixed peg. When $\theta>0$ the dynamics of the economy become more complicated, but KFG's results still hold for θ small enough (by continuity).

An active interest rate defense policy is impossible in the standard KFG model (with $\theta=0$) since UIP implies that the domestic interest rate must remain equal to its foreign counterpart

before the collapse of the currency peg.[5] The wedge in the interest parity condition that we have introduced in the model, on the other hand, gives the authorities an additional degree of freedom in setting the interest rate. Can it be used to postpone—or forestall—the crisis? This is the question we address in the following section.

3. Pegging the interest rate

We assume, for simplicity, that the interest rate is constant before and after the attack, but may jump at the time of the attack: the pre-attack interest rate is set at $\bar{r}$ and the post-attack interest rate is set at $\bar{\bar{r}}$:

$$r_t = \bar{r}, \quad t \leq T ,$$

$$r_t = \bar{\bar{r}}, \quad t > T .$$

We make no assumption about the relative interest rate levels before and after the collapse. The government primary surplus, τ, is constant.

3a. The pre-collapse regime

While both the exchange rate and the interest rate are fixed, the domestic monetary authority intervenes in the domestic bond market and in the foreign exchange market to fix prices. It is no surprise then that with prices fixed, quantities adjust to achieve equilibrium. Asset market equilibrium is characterized by:

$$r_t - r^* = \theta \frac{B_t}{\bar{S}} = \theta \frac{(N_t - M_t + \bar{S} R_t^*)}{\bar{S}} \qquad (8)$$

with M_t constant, equal to $M = \bar{S}\mu \exp(-\alpha \bar{r})$. Foreign exchange reserves, R^*, move to clear the market. Consider the effect of an increase in the foreign interest rate, r^*; it increases the demand for foreign-currency assets, which requires a fully sterilized balancing reserve outflow to accommodate the private portfolio shift at a fixed exchange rate. An increase in r, on the other hand, induces a different balancing operation where the domestic

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[5] This is because the standard KFG model is deterministic. Stochastic extensions of this model, such as in the second part of Flood and Garber (1984b) or Obstfeld (1986), produce a peso effect before the collapse. In these models, however, the interest rate differential remains the passive reflection of devaluation expectations, not the result of an active interest rate defense.

monetary authority purchases international reserves, but more than fully sterilizes the purchase in order to accommodate reduced money demand.

In equation (8), the dynamics of $R*$ are determined by the dynamics of N. At the attack time, $R*$ will jump to preserve asset market equilibrium and avoid a foreseen exchange rate jump. Asset rates of return jump from pre- to post-attack levels but not the exchange rate. A foreseen exchange rate jump would present a risk-free profit opportunity. In certainty, the attack time is determined to ensure no foreseen profits (exchange-rate jump).

With prices and the primary fiscal deficit fixed, debt dynamics become a simple accounting problem. Pre-collapse debt dynamics of debt are given by:

$$N_t = (N_0 + \lambda)\exp(r*t) - \lambda \qquad (9)$$

where λ is:

$$\lambda = \left(\frac{(\bar{r} - r*)^2 - \theta\tau}{\theta r*} - \mu\exp(-\alpha\bar{r}) \right)\bar{S} \qquad (10)$$

(see the appendix). Parameter λ is strictly increasing with $\bar{r}$ and strictly decreasing with τ. Hence, the level of nominal debt at any given time $t>0$ before the speculative attack is strictly increasing with the interest rate and strictly decreasing with real tax receipts.

$$\forall t \in (0, T), \qquad \frac{\partial N_t}{\partial \bar{r}} > 0 \qquad \frac{\partial N_t}{\partial \tau} < 0 \qquad (11)$$

This is sensible. An increase in the interest rate on debt will increase the rate at which debt is accumulated and an increase in taxes will decrease debt accumulation – other things held constant.

3b. The post-collapse regime

Following a collapse, the economy settles (immediately) into a real steady state with constant rates of depreciation, nominal expansion and a constant *real level* of government debt.[6] The way public finance works presently is that the economy jumps from the insufficiently-financed fixed-rate equilibrium which is destined to collapse to an inflationary steady state. As we have assumed the primary surplus, τ, to be constant and since gross

[6] This is where we rule out post-collapse hyperinflationary bubbles and government Ponzi schemes. Without ruling out such anomalies, the timing of collapse is arbitrary. See the appendix for details and see Flood and Garber (1984b) for a discussion of this issue.

seignorage is determined by $\overline{\overline{r}}$, the only remaining balancing variable is the real level of debt, $n=N/S$, which must satisfy:

$$n\left(r*+\theta(n-m)\right)=\overline{\overline{r}}\,m+\tau \qquad (12)$$

where $m=\mu\exp(-\alpha\overline{\overline{r}})$ denotes the real quantity of money in the post-collapse regime (see the appendix). Equation (12) is the steady state ($\dot{n}=0$) government's budget constraint with private behavior incorporated and international reserves set at the post-crisis lower bound, zero. This equation says that the (real) service of government debt must equal gross seignorage revenues plus fiscal receipts.

Equation (12) is a second-order polynomial equation in n, whose unique positive root is a function of the interest rate and fiscal receipts:

$$n=v\!\left(\overline{\overline{r}},\tau\right)\equiv\frac{1}{2}\left\{-\frac{(r*-\theta m)}{\theta}+\sqrt{\frac{(r*-\theta m)^2}{\theta^2}+\frac{4(\overline{\overline{rm}}+\tau)}{\theta}}\right\} \qquad (13)$$

If $\theta=0$ the interest parity wedge disappears and $v(.)$ takes the simple form:

$$v(\overline{\overline{r}},\tau)=\frac{\overline{\overline{r}}\mu\exp(-\alpha\overline{\overline{r}})+\tau}{r*}$$

which is increasing in the level of tax receipts, τ. It is also increasing with the interest rate, $\overline{\overline{r}}$, when the economy is on the increasing branch of the seigniorage Laffer curve, i.e., if the interest rate is lower than $1/\alpha$. If $\theta>0$ things are a bit more complicated (see the appendix) but it remains true—if the slope of the seigniorage Laffer curve is large enough—that:

$$\frac{\partial v}{\partial \overline{\overline{r}}}>0 \quad , \qquad \frac{\partial v}{\partial \tau}>0 \qquad (14)$$

To understand these results, recall that τ is exogenous. To the extent that an increase in the interest rate generates additional seignorage revenue, this revenue supports higher steady-state real debt, hence $\partial v/\partial\overline{\overline{r}}>0$. Similarly, an increase in τ represents a revenue windfall to the government, which also supports higher steady state debt, $\partial v/\partial\tau>0$.

3c. The collapse

The shadow exchange rate at time t , $\tilde{S}_t$, is the value of the exchange such that

$$\frac{N_t}{\tilde{S}_t} = v(\bar{\bar{r}}, \tau)$$

For given post-collapse policies, $\tilde{S}$ is proportional to the state variable N_t. If N starts small but grows without bound then the fixed rate is doomed. The currency peg collapses if and when the shadow exchange rate crosses the fixed peg, i.e., if there is a time T such that:

$$\frac{(N_0 + \lambda)e^{r^*T} - \lambda}{\bar{S}} = v\left(\bar{\bar{r}}, \tau\right) \qquad (15)$$

The collapse is inevitable if nominal debt explodes, i.e., if $N_0 + \lambda > 0$. In that case the time of collapse is given by (15). Several observations are in order.

First, the collapse is essentially the reflection of fiscal imbalance.[7] It is always possible, other things equal, to raise the level of taxes such that $N_0 + \lambda < 0$, which prevents public debt from exploding. The most natural way to defend the currency peg is to fix the underlying fiscal problem.

Second, the model is set up to see if the same result can be achieved using the interest rate. Changing $\bar{r}$ and $\bar{\bar{r}}$ will affect both the left and right-hand sides of equation (15), possibly postponing the collapse—or even removing its occurrence if the equation no longer has a solution. It is easy to see from (15) that *the time of the collapse is decreasing with the pre-collapse interest rate and increasing with the post-collapse interest rate*:

$$\frac{\partial T}{\partial \bar{r}} < 0 \qquad \frac{\partial T}{\partial \bar{\bar{r}}} > 0$$

Raising the interest rate before the attack, and lowering it afterwards, only hastens the collapse of the currency peg. This result is intuitive from the underlying fiscal nature of the crisis. Raising the interest rate before the collapse worsens the government's fiscal problem, since it amounts to financing a stock of low-interest-rate-bearing foreign assets by borrowing at a high interest rate. On the other hand, higher interest rates after the collapse are associated with higher seigniorage revenues, allowing the government to service a larger real debt in

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[7] In this sense the model is in spirit to the fiscal extensions of the KFG framework, see e.g. Buiter (1987). Daniel (2000) recasts the argument in the context of Woodford's "fiscal theory of the price level".

steady state. Before the collapse an increase in the nominal interest rate makes the fiscal situation worse because it is reflected one-for-one in the *real* interest rate (since the price level is constant); after the collapse the same increase in the nominal interest rate improves the fiscal situation by raising the inflation rate, and seigniorage revenues.[8]

An interest rate policy involving a high interest rate before an attack—perhaps as an ill-conceived incentive to speculators to hold domestic currency assets—and a lower rate following the attack is totally self-defeating. While such a policy makes reserves *look good* before the collapse, those reserves are not positive indicators of the health of the fixed rate regime. The only reliable indicator of the health of the fixed rate is the level of government debt, assuming a constant fiscal deficit. Reserves are expensive window dressing here; by accumulating them the government behaves as an insolvent household that would try to impress creditors by financing large cash balances with credit card debt.

To take another analogy, this time with a real wartime defense, raising the interest rate only before the attack is like raising the pay of the army only before the fighting starts and then letting its pay fall back as soon as the action begins. Indeed—the analogy continues—the misguided pre-attack pay raise is less than useless as it exhausts the treasury thereby making it harder to pay the troops when the attack starts.[9]

It might be possible, under some conditions, to prevent the collapse (and not only postpone it) using the interest rate. What is required, however, is a *reduction* in the pre-collapse interest rate, $\bar{r}$. This policy can succeed only if the required reduction does not imply a negative level of reserves, which in turn is possible if the fiscal situation is good enough.

Our results are strong and surprisingly clear. In the concluding remarks that follow the next sections we will discuss the assumptions crucial to those results, in particular that international reserves are inherently useless.

3d. Multiple equilibria

An ill-conceived interest rate strategy not only hastens the collapse, but also can make it self-fulfilling. The collapse time is an endogenous variable and the attack itself may influence government policy. The attack signals the policy to change from $\bar{r}$ to $\bar{\bar{r}}$, which is just the

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[8] The inflation rate increases by less than the nominal interest rate because the shift of domestic bonds from the central bank to investors (induced by lower money demand) must be associated with an increase in the *real* interest rate.

[9] Beating the analogy nearly to death, we note that it breaks down if it takes time to train the troops and get them into an effective defensive position. This is one way perfect capital mobility comes into the model, which is the limiting case that we study.

sort of Salant-style policy nonlinearity that may induce multiple equilibria.[10] To see this point rewrite the shadow rate at t as:

$$\widetilde{S}_t = \frac{N_t}{\frac{\{v(\overline{\overline{r}}, \tau) - v(\overline{r}, \tau)\}}{\Delta r} \Delta r + v(\overline{r}, \tau)}$$

Normally $\frac{\{v(\overline{\overline{r}}, \tau) - v(\overline{r}, \tau)\}}{\Delta r} > 0$ as studied in the derivative above. A decrease in the interest rate, $\Delta r < 0$, after the attack, will, therefore increase the shadow rate. This is precisely the condition that can make a speculative attack self-fulfilling. The attack induces the very policy change that ratifies the attack.

3e. Simulations

We can go further in describing the dynamics of speculative attacks in our model with the help of simulations. Figure 1 shows the dynamics of the exchange rate, money supply and its components before and after a speculative attack. The figure was constructed with the following calibration: $\alpha=1$, $\theta=1/(2\mu)$, $N_0=\mu/2$, $\tau=0$, $\overline{r} = 20\%$, $\overline{\overline{r}} = 10\%$ and $r^* = 5\%$. The fixed parity, $\overline{S}$, was normalized to 1 and μ was treated as a scaling parameter (it was set to 1 in the figure).

The calibration of the structural parameters α and θ was derived from Mexican data in the early 1990s. The value of 1 for the interest rate semi-elasticity of money demand is in line with estimates obtained in the literature (Cuthbertson and Galindo, 1999). Parameter θ is the increase in the domestic interest rate that is required to attract one unit of foreign capital. Its calibration is based on Werner's (1996) finding that in the two years leading to the 1994 Mexican peso crisis, increasing the share of peso-denominated debt (CETES) in total debt (CETES+TESOBONOS) required a 0.25 percentage point increase in the interest rate on one-month CETES. Hence the dollar reserves attracted by a 1 percentage point rise in the one-month peso interest rate can be estimated to 4 percent total debt, or 2 percent of M1, implying $1\% = \theta\ 2\%\ \mu$, or $\theta=1/(2\mu)$.[11]

Figures 1b-c highlight the similarities and the differences between KFG and our model. Like in KFG, the exchange rate shifts without discontinuity to a path with a constant rate of

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[10] This type of multiplicity was pointed out in Flood and Garber (1984a) following comments made by Steven Salant. Obstfeld (1986) pioneered using the idea in the exchange rate context where it has had a large following; see Flood and Marion (1999) for a survey.

[11] In 1992-93 total debt (CETES+TESOBONOS) amounted to 20 US$ bn and M1 to 40 US$ bn in average (source: IFS and Bank of Mexico).

depreciation, while reserves jump down to zero, at the time of the attack. Unlike in KFG, money supply jumps up because of the decrease in the interest rate. Domestic credit also jumps up, so as to equate money supply and money demand at the post-collapse interest rate.

3f. Is this model helpful for interpreting the 1990s Asian crises?[12]

Yes, but it leaves out a crucial part of the story. In the model, fiscal problems lead to currency crises and effective long-term currency-peg defense is a fiscal issue. In the East - Asian crises of the late 1990's countries' on-book fiscal positions were strong and monetary policy was not excessively expansionary (Berg ,1999). Many of the countries that went into currency crisis experienced problems, however, in the heavily extended banking and private corporate sectors.

In expanded KFG, the only way banking collapse and private-sector failures translate into a currency-peg collapse is if the private sector believes that off-book government-bailout promises suddenly increased effective government debt (Burnside, Eichenbaum and Rebelo, 1998). If perceived government debt jumps unexpectedly, the shadow exchange rate jumps unexpectedly also and the currency peg may collapse.

The currency weakens in this scenario because future monetization (seignorage) is required to support suddenly increased government commitments. The element that we leave out, of course, is how the Asian banks and large private companies got into trouble in the first place, and whether their troubles were aggravated by raising the interest rate. Once the private collapse begins, however, the standard KFG model translates the problems easily to a currency attack via the financing required to service government promises.

4. Concluding comments

We have studied an extension of the KFG model and found that increasing the domestic-currency interest rate prior to a speculative attack, with no other policy adjustments, is never an effective exchange-rate defense. Indeed such a policy is self defeating—it always shortens the fixed-rate epoch. Promising to increase the interest rate after the attack (and actually doing so) is nearly always an effective way to defer the attack—it is the interest rate defense.[13]

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[12] This section has benefited from discussions with Michael Dooley, Peter Garber and Nancy Marion.

[13] To keep the analysis simple, we have not studied the possibility of temporary interest rate responses to temporary shocks. The model is well-suited to such an investigation, but at the price of algebraic complexity.

Before the attack, raising the rate increases debt service and draws in international reserves, but *international reserves are a bad investment presently*—a fiscal drag that weakens the currency. We recognize that this can't be the whole story. Sensible policymakers and policy advisors worldwide are comforted uniformly by high reserve balances that have poor portfolio performance. There must, therefore, be some return to reserves that we are missing. It could be, for example, that raising the interest rate is the only way to defend the fixed exchange rate peg when there are doubts on its sustainability—a defense which might turn out to be successful *ex post* if the doubts are dispelled by appropriate policy actions or good news. Explicit considerations of such strategies would require making the model stochastic. We suspect the missing return also might involve short-term capital stickiness that simply does not enter existing perfect capital mobility models like ours.

APPENDIX

A) Solving for the pre-collapse debt path

After some substitutions equation (5) becomes:

$$\dot{N}_t = \bar{r}(N_t - M) + (\bar{r} - r^*)\bar{S}R_t^* - \bar{S}\tau \qquad (A.1)$$

Since M is constant during the fixed rate epoch, when r is fixed, tracking N requires that we

$$\bar{S}R_t^* = \frac{(\bar{r} - r^*)\bar{S}}{\theta} - (N_t - M),$$

keep track of reserves. Solving for $\bar{S}R_t^*$ in equation (8),
and plugging this expression into (A.1) gives:

$$\dot{N}_t = r^*(N_t + \lambda) \qquad (A.2)$$

where λ is given by equation (10). Equation (9) then directly follows from the integration of equation (A.2).

B) Solving for the post-collapse debt path

Reserves are set to zero and the interest rate is constant, equal to $\bar{\bar{r}}$. Simple manipulations of equations give the following first-order differential equation for real debt:

$$\dot{n} = \theta n^2 - (\theta m - r^*)n - \bar{\bar{r}}m - \tau \qquad (A.3)$$

with $m = \mu \exp(-\alpha\bar{\bar{r}})$ The right-hand-side of (A.3) is a second-order polynomial in n, with one unique positive root v, given by equation (13). This root can be characterized graphically as the point where the curve corresponding to the r.h.s. of (A.3) intersects the x-axis. The curve is strictly increasing at this point, implying that $n=v$ is an unstable solution. Hence, real debt goes to infinity if $n_T>v$ and converges to a negative level if $n_T<v$. We can rule out the first case on the ground that it violates the no-Ponzi game condition for the government, and rule out the second case by assumption. As a result the level of real debt must be equal to v at the time of the collapse. In order to prove the inequalities in (14), note that increasing τ lowers the r.h.s. of (A.3) and so shifts its intersection with the x-axis to the right—i.e., this increases v. Differentiating the r.h.s. of (A.3) with respect to the interest rate shows that increasing $\bar{\bar{r}}$ also increases v provided that $\alpha(\bar{\bar{r}} + \theta v) < 1$.

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