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RESEARCH ARTICLE

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Convertibility risk: the precautionary demand for foreign currency in a crisis

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Abstract This paper presents theoretical work linking money demand to the perceptions of households about the risk that domestic currency may become inconvertible or that it may be devalued. An empirical investigation of the size of this effect is carried out using monthly data for Korea to estimate an augmented demand-for-money equation. It is found that the fear of inconvertibility arising from the 1997 Korean currency crisis may have caused broad money demand to fall by 4–5% points, equivalent to the loss of reserves of \$6–7.5 billion (or about 30% of reserves as measured at end-November 1997).

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1 Introduction

Much controversy surrounds the IMF's response to the worldwide financial crises of the 1990s. Too frequently, a simple blanket indictment suggests either that the IMF was misguided in its advice to the affected countries or that it insisted on excessively high interest rates to combat exchange rate depreciation (Stiglitz 2002). This paper suggests that careful examination of the details of policies followed may lead to improved policy recommendations, if indeed mistakes were made. Furthermore, it suggests possible early warning indicators of such crises.

Our understanding of the nature of foreign exchange crises has certainly deepened following the recent episodes in Asia (Thailand, Indonesia, Malaysia and Korea) and elsewhere (Turkey, Russia, Argentina, Brazil, Uruguay). Several indicators are being used in attempts to identify countries that may be vulnerable to crises, such as a large current account deficit, a sustained loss of competitiveness, and low external reserves. Work by Berg (1999) and others on early warning systems (EWS) has produced econometric evidence underscoring the usefulness of such indicators in predicting foreign exchange crises. Despite these advances, however, the specific channels through which currency crises are propagated remain less well understood, weakening the ability of policymakers to design appropriate preventive policies. One challenge is deciding on which set of vulnerability indicators is the most relevant for a particular country, and the work on EWS, although useful, is based much more on statistical concepts than on a well understood theoretical framework. Hence, even *ex post*, it is often difficult to assign a quantitative weight to the importance of various factors in explaining the incidence and severity of a crisis.

This paper investigates an empirically important, yet relatively neglected, channel of vulnerability, namely the drop in the demand for money that arises from fear of a crisis-induced inconvertibility of domestic currency. According to this argument, if domestic residents require access to foreign exchange for transactions purposes (a cash-in-advance constraint) and come to believe that there is a significant risk of interference with normal market access, they will attempt to protect themselves by increasing their precautionary demand for foreign currency. This response will manifest itself in a simultaneous drop in the demand for domestic money and shrinkage of reserve asset holdings by the central bank. In this paper, we demonstrate this result in a two-period optimizing model that takes the probability of inconvertibility as exogenous to the public. To stem reserve losses, monetary authorities may resort to an interest rate defense. We compare the effectiveness of an interest rate defense against reserve loss with the option of currency devaluation. We find that as long as the demand for imported goods that underlies the foreign currency's cash-in-advance constraint satisfies an Inada condition, an interest rate defense is not very helpful as a response to inconvertibility risk. By contrast, an interest rate defense is much more effective in dealing with devaluation risk.

This insight – the contrasting response of domestic money demand to an interest rate defense under convertibility and devaluation risks – carries an important policy message. Faced with increased pressure on their currency, macroeconomic policymakers may be tempted to limit the quantities of foreign exchange made available to the public in the foreign exchange market. Yet such administrative measures may be counterproductive. If the public senses that the authorities are more likely to resort to nonmarket measures to "conserve" their stock of international reserves, convertibility risk will be heightened, and money demand will become less responsive to an interest rate defense of a given size. Policy actions that impair the purchasing power of the currency over foreign goods will enhance the fears of domestic residents and intensify the very currency flight the authorities seek to avoid. In this sense, impaired currency convertibility may be likened to a "limping" currency standard. See, for example, Aliber (1973) and McKinnon (1974) where the impaired gold–dollar link is named the "limping" dollar standard. In these circumstances, it is preferable for the authorities to attack the direct causes of the problem by restoring full convertibility, albeit at a depreciated exchange rate.[1]

Our focus on convertibility risk for current transactions as a factor in recent crises is grounded in experience. Although the convertibility for current transactions of the currencies that came under attack in Asia and elsewhere was not an issue in a *legal* sense, anecdotal evidence suggests that de facto suspensions did occur in several counties. When fixed parities came to be doubted, the monetary authorities in more than one country responded by limiting the ability of market participants to obtain foreign currency rather than by letting their currency float, at least initially. The response of the authorities during the Korean crisis illustrates this pattern. In the height of the crisis in December 1997, trading sessions in the exchange market were typically very short. The market would open at 10 a.m. every morning, immediately drop 5% (the allowable band), and close in about 10-min, leaving many unsatisfied dollar buyers. Likewise, in Russia in 1998, where convertibility was generally maintained in the days before the August 17, 1998 devaluation, some banks resorted to freezing dollar withdrawals and closed exchange points (Oxford Analytica 1998). After the attempt at controlled devaluation failed, foreign exchange trading was brought to a halt on August 26 when the Central Bank of Russia (CBR) terminated the fixing of the exchange rate in the Moscow International Currency Exchange (MICEX) auctions.[2] The foreign exchange market reopened on September 3 after the CBR had abolished the exchange rate band the previous day and let the exchange rate float.[3] The situation in Ukraine in the

[1] The objective of the paper is limited to defining, characterizing and estimating the magnitude of convertibility risk. The broader – and more challenging – question of the welfare costs of inflation under conditions of currency substitution is not addressed. See Cavalcanti and Villamil (2003) and the references therein for such an analysis.

[2] To relieve exchange market pressures, on August 17, 1998, the Russian government widened the exchange rate band from 5.3–7.1 to 6.0–9.5 Russian rubles per US dollar.

[3] Subsequently the CBR introduced wide-ranging administrative measures to suppress demand for foreign exchange, even for current account purposes. Surrender requirements on exporters were raised, advanced import deposit requirements were introduced, and the ruble accounts of nonresident banks with domestic banks were not convertible freely into foreign exchange.

fall of 1998 was broadly similar. Similarly, in Argentina on December 1, 2001, in response to a surge in the demand for U.S dollars, the authorities limited domestic residents‘ access to US currency through the imposition of banking and exchange controls designed to protect currency convertibility, interfering with normal business activity.[4] Despite these steps, the crisis did not abate.

While informal evidence is suggestive, formal econometric techniques are needed to establish the empirical relevance of convertibility risk (as opposed to devaluation risk or the risk of capital controls). Our approach is to estimate a money demand equation that includes variables intended to capture actual or expected inconvertibility. We modify a conventional time series money demand equation for Korea by including variables linked to the probability that the domestic currency becomes inconvertible. Such variables are helpful in explaining money demand, and especially the large drop around the time when the foreign exchange crisis afflicted Korea (toward the end of 1997). We also conduct a counterfactual simulation to measure the impact of these "crisis" variables on money demand. Finally, conclusions are drawn regarding the quantitative importance of inconvertibility in crises, as well as more tentative conclusions on how to design policies to minimize external vulnerability given the findings in this paper.

The rest of this paper is organized as follows. Section 2 presents the model of currency convertibility risk and the effects of an interest rate defense. Section 3 turns to the demand for domestic and foreign currency in the presence of devaluation risk and compares the workings of an interest rate defense in this case to the case of convertibility risk. Section 4 describes the properties of currency demand schedules under convertibility and devaluation risk for the constant relative risk aversion (CRRA) class of preferences. Section 5 presents our empirical work while Section 6 draws final conclusions. Appendix A describes our data sources; Appendix B derives the currency demands for the CRRA case.

2 A model of currency inconvertibility

2.1 The model

Consider a small open endowment economy that lasts for two periods, denoted t and $t{+}1$. There are two nonstorable commodities each period: good x is domestically available and internationally tradable while good y is imported from the rest of the world. The representative domestic agent is endowed with W units of good x in period t and consumes the domestic and imported good at $t{+}1$. Her preferences over the two commodities are represented by a utility function $u(x_{t+1}, y_{t+1})$ that exhibits positive and diminishing marginal utilities and satisfies an Inada condition for each good. The agent has access to a domestic-currency asset and a foreign-currency asset. She is subject to cash-in-advance constraints that require her to use domestic currency to buy home goods and foreign currency to buy imports. Domestic currency may be obtained in the date-t home-country currency market

[4] Russia's experience is described in *IMF Country Report* No. 1999/100 (paragraph 98, September 1999). On Ukraine, see *IMF Country Report* 1999/42 (paragraph 89, May 1999). See www.imf.org. On Argentina, see "Argentina's Move," Financial Times, December 3, 2001.

at price $1/p_t$. [5]. Foreign currency to purchase imports at t+1 can be obtained in one or, perhaps, two ways. The domestic resident can sell her endowment of good x for foreign currency at t and hoard these balances until t+1. Alternatively, she can obtain foreign currency at t+1 by selling part of her home-currency balance at the t+1 foreign exchange market. This second strategy is risky as the authorities may suspend foreign currency trading in the date t+1 foreign exchange market.

A precautionary motive for holding foreign-currency assets is introduced in a simple manner. Foreign-currency assets are dominated in rate of return but are voluntarily demanded as they help by domestic residents insulate themselves from the risk that domestic currency will become inconvertible in the future. The authorities maintain the exchange rate at unity in period t. The gross real return R_t (in terms of good x) earned by domestic asset is assumed to exceed unity. This gross real return is given by $R_t = (1 + i_t)/(1 + \pi_t)$, where i_t is the net nominal domestic interest rate and $\pi_t = (\mathrm{p}_{t+1} - \mathrm{p}_t)/\mathrm{p}_t$ is the net nominal inflation rate between t and t+1. Without loss of generality, the real gross return (in terms of good y) on foreign-currency assets is assumed to be unity.[6] Under a fixed exchange rate and in the absence of convertibility risk, demand for foreign-currency would be zero. Households would maximize their wealth by investing in domestic-currency assets that offer high real returns and would buy the foreign-currency they need to finance imports in the spot foreign exchange market.

We now establish that convertibility risk generates a precautionary demand for foreign-currency hoards. Let $\alpha_{t+1} \in [0, 1]$ be the exogenous probability that the domestic currency will become inconvertible at $t + 1$, in which case domestic residents will be unable to convert domestic currency balances into the foreign currency they need to finance consumption of imports. Convertibility might be suspended for a number of reasons – because the monetary authority runs short of foreign exchange or because it decides to ration foreign currency rather than allowing its price to rise to clear the market. The decision problem facing a young household entering period t is to select a level of real domestic-currency balances, $m_t = h_t/\mathrm{p}_t$, real precautionary foreign-currency balances, f_t, and real foreign-currency purchases or sales in the date t+1 foreign exchange market, b_{t+1}, to maximize

$$E_t\{u(x_{t+1}, y_{t+1})\} \equiv (1 - \alpha_{t+1})u(x^1_{t+1}, y^1_{t+1}) + \alpha_{t+1}u(x^2_{t+1}, y^2_{t+1}) \qquad (1)$$

[5] As regard the supply of money in the economy, it is assumed that the central bank starts out with a given portfolio of net international reserves and other net foreign assets (*NFA*) and net domestic assets (*NDA*). The supply of money (M) satisfies $M = NFA + NDA$. Our model requires cash in advance to buy domestic and foreign goods totaling $h/p + f = W$, where the exchange rate $e = 1$. Thus the total demand for money is W. What varies is the amount demanded in the form of domestic or foreign currency. By setting the interest rate at R and the exchange rate at $e = 1$, the central bank is assuring that it will accommodate the demands by supplying the requisite amounts of domestic and foreign currency. As the demand for foreign currency goes up, the central bank's reserves will go down, leaving the total money supply constant for a given interest rate. The pressures that force the government to suspend convertibility – near exhaustion of reserves or other events in the foreign exchange market – as well as the origin or distribution of profits or losses on the central bank's portfolio are not the focus of this paper and are not explicitly modeled.

[6] Real returns on investment projects (in terms of domestic goods) are normally relatively high in developing countries while risk-free real net interest rates in mature countries (in terms of their own goods) are typically quite low.

subject to the following constraints: At date t,

$$\frac{h_t}{p_t} + f_t = W; \tag{2}$$

At date $t+1$, with probability 1-α_{t+1},

$$x^1_{t+1} \leqslant \frac{h_t(1+i_t)}{p_{t+1}} - b_{t+1}; \quad y^1_{t+1} \leqslant f_t + b_{t+1} \tag{3}$$

At date $t+1$, with probability α_{t+1},

$$x^2_{t+1} \leqslant \frac{h_t(1+i_t)}{p_{t+1}}; \quad y^2_{t+1} \leqslant f_t$$

The quantity b_{t+1} is the domestic resident's planned purchases (sales if negative) of foreign currency in the spot foreign exchange market in period $t+1$ if convertibility is maintained. Using the budget constraints (3) and (4) at equality and the definitions of R_t, m_t, and b_{t+1}, the agent's expected utility can be written in terms of the asset demands as follows.

$$(1-\alpha_{t+1})u\left[(W-f_t)R_t - b_{t+1}, f_t + b_{t+1}\right] + \alpha_{t+1}u[(W-f_t)R_t, f_t]. \tag{4}$$

As a preliminary exercise, consider the situation in which the risk of inconvertibility is zero, $\alpha_{t+1} = 0$. In this case, the problem is simply to maximize $u\,[(W-f_t)R_t - b_{t+1}, f_t + b_{t+1}]$. If $R_t > 1$ and the agent cannot borrow foreign-currency assets at t, the agent will select $f_t = 0$, $m_t = W$ and b_{t+1} solves max $u\left[WR_t - b_{t+1}, b_{t+1}\right]$.[7] Stated differently, if the domestic real interest rate is positive, precautionary demand for foreign currency will be zero and all foreign currency for import purchases will be obtained in the spot foreign exchange market at $t+1$.

A specific example is useful to fix the ideas. Let utility be $u(x, y) = \gamma \ln(x) + (1-\gamma)\ln(y)$. Demand schedules are $x = \gamma[f + R(W-f)]$ and $y = (1-\gamma)[f + R(W-f)]$. Reduced-form utility is $U(f) = \gamma \log(\gamma) + (1-\gamma)\log(1-\gamma) + \log[f + R(W-f)]$. Note that $U'(f) = (1-R)[f + R(W-f)]^{-1} < 0$ if $R > 1$. The case $\alpha_{t+1} = 0$ leads to a corner solution: f_t=0 and $b_{t+1} = (1-\gamma)R_t W$. At the other extreme, if inconvertibility is inevitable ($\alpha_{t+1} = 1$), then households plan to pay for their imports exclusively by building up precautionary balances, i.e., $b_{t+1} = 0$ and f_t maximizes $u[(W-f_t)R_t, f_t]$. From the Inada conditions, the solution for f_t is interior and satisfies

$$\frac{u_2}{u_1}[(W-f_t)R_t, f_t] = R_t, or f_t = (1-\gamma)W.$$

More generally, if α is positive but less than unity, f_t will be guaranteed to be positive because of the Inada condition on y which requires that $\partial u/\partial y \to \infty$ as $y \to 0$. The first-order conditions for an interior optimum involving f_t>0 are:

[7] If households had access to the international capital market at a gross interest rate of unity, they would have incentives to borrow foreign currency and invest domestically.

$$b_{t+1} : (1-\alpha_{t+1})\big[-u_1(x^1, y^1) + u_2(x^1, y^1)\big] \\ +\alpha_{t+1}\big[0 \cdot u_1(x^2, y^2) + 0 \cdot u_2(x^2, y^2)\big] = 0 \tag{5}$$

$$f_t : (1-\alpha_{t+1})\big[-R_t u_1(x^1, y^1) + u_2(x^1, y^1)\big] \\ +\alpha_{t+1}\big[-R_t u_1(x^2, y^2) + u_2(x^2, y^2)\big] = 0 \tag{6}$$

The first condition equates the marginal rate of substitution between goods x and y to their relative price (unity) in the convertibility state. It can be written simply as

$$u_1(x^1, y^1) = u_2(x^1, y^1). \tag{7}$$

The second condition, equation (6), reflects the weighing of risk and return from holding safe but barren foreign currency and productive but risky domestic currency. Substituting (7) into (6) and simplifying yields the precautionary demand for foreign currency:

$$(1-\alpha_{t+1})(R_t - 1)u_1(x^1, y^1) = \alpha_{t+1}\big[-R_t u_1(x^2, y^2) + u_2(x^2, y^2)\big] = 0. \tag{8}$$

Total differentiation with respect to α_{t+1} and using the notation $u^1 = u(x^1, y^1)$, etc., yields

$$\frac{df_t}{d\alpha_{t+1}} = \frac{1-R_t}{\alpha_{t+1}} \times \frac{u_2^{\mathbf{1}}}{\alpha_{t+1}[R_t^2 u_{11}^{\mathbf{2}} - R_t(u_{12}^{\mathbf{2}} + u_{21}^{\mathbf{2}}) + u_{22}^{\mathbf{2}}]} > 0, \tag{9}$$

since the denominator is negative. Thus an increased risk of currency inconvertibility leads to increased precautionary holdings of foreign currency assets at the expense of domestic money.

This result can be illustrated with a CES utility function with elasticity of substitution between home and foreign goods $\theta = 0.8$, $R = 1.2$, $W = 10$, and the share of home goods in the utility function $\gamma = 0.7$. As the risk of inconvertibility rises, the share of assets held in foreign currency rises from near zero to almost 30% (Fig. 1). There are two lessons from this analysis. First, the volume of transactions in the foreign exchange market (b) declines and the demand for foreign currency (f)

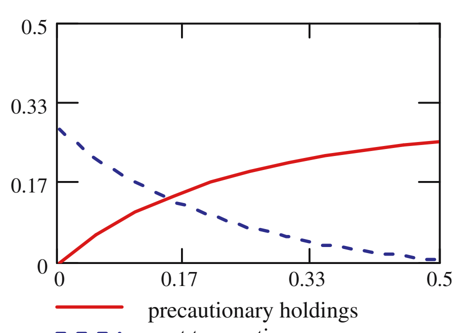

Fig. 1 Inconvertibility risk: share of assets held in foreign currency

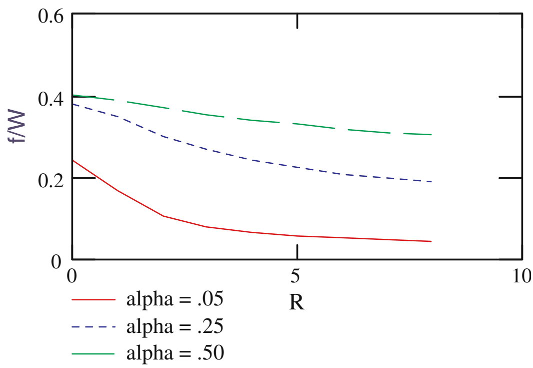

Fig. 2 Interest rate defense: the share of assets held in foreign currency (Cobb–Douglas preferences $u(x, y) = \ln(x) + \delta \ln(y)$, $\delta = 0.7$, R varies from 1.05 to 10)

rises as the crisis probability(α) increases. This provides an insight that could be useful in designing early warning systems: changes in the volume of transactions in emerging economies' foreign exchange markets should be monitored closely as they could contain useful information regarding the probability of crisis anticipated by market participants. Second, the observation that f rises sharply with the probability of crisis is important in considering the feasibility and desirability of an interest rate defense. Let $u(x, y) = \ln(x) + \delta \ln(y)$, where $\delta > 0$ is the weight of imported goods in preferences. Asset demands are then given by:

$$b_{t+1} = \frac{\delta}{1+\delta} R_t W - \frac{1+\delta R_t}{1+\delta} f_t \tag{10}$$

$$\left(\frac{f_t}{W}\right)^2 - \left(1 + \frac{\alpha\delta}{1+\delta} + \frac{\alpha}{R-1}\right)\left(\frac{f_t}{W}\right) + \frac{\alpha\delta R}{(R-1)(1+\delta)} = 0. \tag{11}$$

In equation (11), the valid solution to the optimization problem is the smaller root of the quadratic, which is less than unity. This example highlights, first, the inverse relationship between b and f (see equation (10)). Second, the demand for foreign currency rises sharply with the probability of crisis. At a 5% real interest rate, agents with log preferences facing a 5% probability of crisis would hold 25% of their wealth in foreign currency. If the crisis probability rises to 50%, the share of foreign currency in the agent's portfolio rises to 40%. While these particular numbers refer to the Cobb–Douglas case, the main result – that the share of foreign currency assets rises steeply as the probability of crisis increases – is robust so long as an Inada condition applies to the consumption of imported goods. This assumption appears to be realistic in most developing countries. The example also illustrates that the demand for foreign currency is higher the larger is the weight of imports in preferences. Hence, the vulnerability due to inconvertibility risk is greater the more dependent on imports an economy is. Finally, the opportunity cost of holding foreign currency depends on the domestic real interest rate. We now turn to examine this issue in detail.

2.2 An interest rate defense

A central bank's main weapon during a currency crisis is to raise the short-term interest rate it controls, which raises demand for domestic assets and tends to avert or at least delay the crisis. The feasibility and optimality of raising interest rates to counter a currency crisis is the subject of a growing literature. Krugman (1979) assumed that the central bank is passive. Flood and Jeanne (2000) analyzed an interest rate defense in the Krugman–Flood–Garber model and concluded that it is never effective. In their model, an interest rate defense worsens the fiscal situation and helps bring the crisis forward. Drazen (1999) and Lahiri and Végh (2000) argue that the relationship between the exchange rate and the interest rate is nonlinear. In Drazen's model, in which higher interest rates have signaling effects, higher interest rates may signal either that the authorities are more or less able to defend a peg depending on speculators' information sets. Lahiri and Végh focus on the output and budgetary costs of an interest rate defense in a general equilibrium shopping-time monetary model in which non-cash, interest-bearing financial assets are part of money demand. They find that raising interest rates beyond a certain point raises public debt service or lowers output and could bring forward the crisis.

In our model, an interest rate defense of the domestic currency could be effective in offsetting the increase in precautionary demand for foreign currency associated with an increase in the probability of a crisis. Unfortunately, however, this strategy is most effective when the probability of crisis is low, which is when it is least needed. For example, when the probability of a crisis is 5%, a tripling of real interest rates from 10 to 30% is sufficient to halve f from 16 to 8% of income. When the crisis probability is high, on the other hand, even massive hikes in real interest rates cannot fully offset the resulting increase in the precautionary demand for foreign currency. If α rises to 50%, raising interest rates to 1,000% only succeeds in lowering f from nearly 40% to nearly 30% of income. Things are nearly impossible for the monetary authority if the convertibility crisis is viewed as nearly inevitable, in which case α approaches unity. In such cases, even massive increases in real interest rates would be incapable of reversing the currency shift and would likely involve large economic and budgetary costs. Again, while the specific numbers depend on the particular utility function, the general result – the ineffectiveness of an interest rate defense to stem flight from the domestic currency when inconvertibility risk is high – is due to the Inada condition on imported goods. This result is therefore robust to the specification of the utility function.

The main message of this: it is absolutely crucial for the monetary authorities to deal with the root causes of currency flight by allaying the fears of domestic residents that drive their demand for foreign currency, namely that domestic currency may become inconvertible and hence be of limited value in accessing needed imports. Convertibility can be maintained while allowing pressures on the currency to be released by a discrete devaluation, as discussed in Section 3. In such a scenario, the required depreciation of the currency is dictated by the elasticity of supply of foreign currency with respect to the price. However, if the central bank is not willing to allow the exchange rate to move enough to elicit the needed supply (or dampen the demand sufficiently) then the remaining options are for the central bank to initiate adjustment via some combination of interest rates or expenditure restriction, possibly in conjunction with a program of financial stabilization that provides the government with a financing package from the IMF and other official creditors.

3 Devaluation risk

In this section we consider in detail a policy of discrete devaluation as an alternative to suspending currency convertibility. While in principle devaluation risk could exist in parallel (and be positively or negatively correlated) with convertibility risk, it is of some interest to compare the impact on the demand for domestic assets of a devaluation as an alternative to declaring the currency inconvertible. We show that while devaluation risk also generates a precautionary demand for currency, the strength of the currency substitution it induces is weaker and can be more easily countered via an interest rate defense. Moreover, the extent of the devaluation can be traded off against the magnitude of the interest rate hike required for a successful interest rate defense of the currency.[8]

The setup is as described in the inconvertibility case. The value of the domestic currency in terms of US dollars in period t is fixed at unity: $e_t = 1$; domestic agents expect the currency peg to be maintained with some probability: $e_{t+1} = 1$ with probability $1 - \alpha_{t+1}$, and $0 < e_{t+1} < 1$ with probability α_{t+1}. Agents are competitive in the spot market for foreign exchange, so they can buy or sell unlimited amounts of domestic for foreign currency. They are also able to borrow unlimited amounts at the prevailing interest rate, subject only to their wealth constraint. Using the same notation as in Section 2, the problem of domestic households is to maximize equation (1) subject to equation (2) and

$$x^1_{t+1} \leqslant \frac{h_t(1+i_t)}{p_{t+1}} - b^1_{t+1} \tag{12}$$

$$y^1_{t+1} \leqslant f_t + b^1_{t+1} \tag{13}$$

$$x^2_{t+1} \leqslant \frac{h_t(1+i_t)}{p_{t+1}} - b^2_{t+1} \tag{14}$$

$$y^2_{t+1} \leqslant f_t + e^2_{t+1} b^2_{t+1}. \tag{15}$$

To solve this problem, we again proceed in two steps. First, second-stage household decision rules are derived (the b values), taking as given the first-stage choices (f and m). Then the first stage decision rules are derived taking into consideration agents' second-stage best responses. In the second stage agents treat m_t, f_t and e^i_{t+1} as given and select b^i_{t+1} to maximize

$$u[R_t m_t - b^i_{t+1}, f_t + e^i_{t+1} b^i_{t+1}]. \tag{16}$$

[8] See Ghosh and Basurto (2000) for a discussion of the exchange rate-interest rate nexus in the Asian crisis.

The solution $b^i_{t+1} = b^i_{t+1}(f_t, e^i_{t+1})$ satisfies

$$-u_1[x^i_{t+1}, y^i_{t+1}] + e^i_{t+1} \cdot u_2[x^i_{t+1}, y^i_{t+1}] = 0 \tag{17}$$

In the first stage, agents choose m_t and f_t to maximize expected utility taking into account their choices of b^i_{t+1}. Expected utility as a function of f_t is:

$$\begin{aligned}&(1-\alpha_{t+1})u\big[(W-f_t)R_t - b^1_{t+1}(f_t),\, f_t + b^1_{t+1}(f_t)\big]\\ &\quad +\alpha_{t+1}u\big[(W-f_t)R_t - b^2_{t+1}(f_t),\, f_t + eb^2_{t+1}(f_t)\big].\end{aligned} \tag{18}$$

In this problem, f is the safe asset, earning a gross real return (in terms of good y) of 1, while m is the risky asset, earning a gross real return (in terms of good x) of $R > 1$ with probability $1-\alpha$ and $R \cdot e$ with probability α. An interior solution exists if foreign currency is not a dominated asset: if $e \cdot R$ were greater than or equal to 1, agents would borrow arbitrarily large amounts of foreign currency during the planning period, invest the proceeds in domestic assets and enjoy arbitrarily large expected utility: $eR_t \geqslant 1 \Rightarrow f_t = -\infty, m_t = +\infty$. On the other hand, demand for domestic assets vanishes if the expected return of m is equal to the return of the safe asset: $(1-\alpha)R_t + \alpha e R_t = 1 \Rightarrow m_t = 0$. Moreover, $R_t < (1-\alpha+\alpha e)^{-1}$ implies $m_t < 0$ and $f_t > W$. In this last case, agents would sell their entire endowment plus borrowed funds in the foreign exchange market and hoard the foreign exchange proceeds. In light of these considerations, an interior solution in which $eR_t < 1$ is characterized by

$$\begin{aligned}&(1-\alpha_{t+1})\left[u^1_1 \cdot \left(-R_t - \frac{\partial b^1_{t+1}}{\partial f_t}\right) + u^1_2 \cdot \left(1 + \frac{\partial b^1_{t+1}}{\partial f_t}\right)\right]\\ &\quad +\alpha_{t+1}\left[u^2_1 \cdot \left(-R_t - \frac{\partial b^2_{t+1}}{\partial f_t}\right) + u^2_2 \cdot \left(1 + e\frac{\partial b^2_{t+1}}{\partial f_t}\right)\right] = 0.\end{aligned} \tag{19}$$

The FONC for the second-stage problem can be used to simplify expression (19). This leads to the following tangency condition, which can be used to derive the precautionary demand for f :

$$\frac{1-\alpha_{t+1}}{\alpha_{t+1}} \cdot \frac{u^1_1}{u^2_1} = \frac{e^{-1} - R_t}{R_t - 1}. \tag{20}$$

From equation (20) it is evident that the demand for f will depend on the difference between the expected returns on foreign and domestic currency assets:

$$\alpha_{t+1}(e^{-1} - R_t) + (1-\alpha_{t+1})(1-R_t). \tag{21}$$

4 A CRRA economy

4.1 Currency demands

Analytical solutions to the portfolio problem are possible for the CRRA class of preferences. Let

$$u(x, y) = \frac{x^{1-\sigma}}{1-\sigma} + \delta\frac{y^{1-\sigma}}{1-\sigma}, \sigma \neq 1;$$

and

$$u(x, y) = \log(x) + \delta \log(y), \sigma = 1.$$

If $\sigma > 0$, these preferences feature risk aversion and lead to smooth asset demands that correspond to the ones described by Sargent (1987, Chapter 8). Consumer demands in state $i = 1, 2$ are

$$x^i = \frac{1}{e^i + \left(\delta e^i\right)^{\frac{1}{\sigma}}} \left[f + e^i (W - f) R\right] \tag{22a}$$

$$y^i = \frac{\left(\delta e^i\right)^{1/\sigma}}{e^i + \left(\delta e^i\right)^{1/\sigma}} \left[f + e^i (W - f) R\right]. \tag{22b}$$

These schedules are positive in the f-interval $f_0 \leqslant f \leqslant f_1$, where $f_0 \equiv -eR/(1 - eR)\ W$, $f_1 \equiv R/(R - 1)W$. Assuming $f_0 \leqslant f \leqslant f_1$, Expected Utility is a strictly concave function of f if and only if $\sigma > 0$. In this case the unique maximum f^* is given by

$$f^* = RW \frac{\rho\left[\frac{\alpha(e^{-1}-R)}{(1-\alpha)(R-1)}\right]^{\frac{1}{\sigma}} - 1}{\rho\left[\frac{\alpha(e^{-1}-R)}{(1-\alpha)(R-1)}\right]^{\frac{1}{\sigma}} (R - 1) + \left[e^{-1} - R\right]}, \tag{22}$$

where the parameter $\rho > 0$ is defined by

$$\rho = \frac{1 + \delta^{\frac{1}{\sigma}} e^{\frac{1-\sigma}{\sigma}}}{1 + \delta^{\frac{1}{\sigma}}}. \tag{23}$$

The value of ρ depends on the preference parameter σ and the extent of devaluation e. $\rho = 1$ if $\sigma = 1$, while $\rho > 1$ if $\sigma > 1$ and $e < 1$.

As can be seen from equation (22), the size of f depends on the ratio of the expected returns on foreign and domestic currency assets, $\alpha(e^{-1} - R) + (1 - \alpha)(1 - R)$.

In the log case $\sigma = \rho = 1$, and (31) reduces to $f^* \equiv WR\left[\frac{\alpha}{R-1} - \frac{1-\alpha}{e^{-1}-R}\right]$.

4.2 Comparative statics

Comparative static exercises were conducted by varying the parameters (α, e, R, σ): Figure 3 draws a family of demand schedules for foreign currency, one for each value of σ, as functions of the probability of crisis α. The calculations assume a 40% devaluation (e =0.6) and a 20% domestic real interest rate (R=1.2).

Several properties of the f schedules stand out: (1) As in the inconvertibility case, the share of foreign currency in the optimal portfolio rises with the probability of devaluation. (2) However, unlike the inconvertibility case, where $f > 0$ for all values of α, in the devaluation case $f < 0$ for "low" values of the crisis

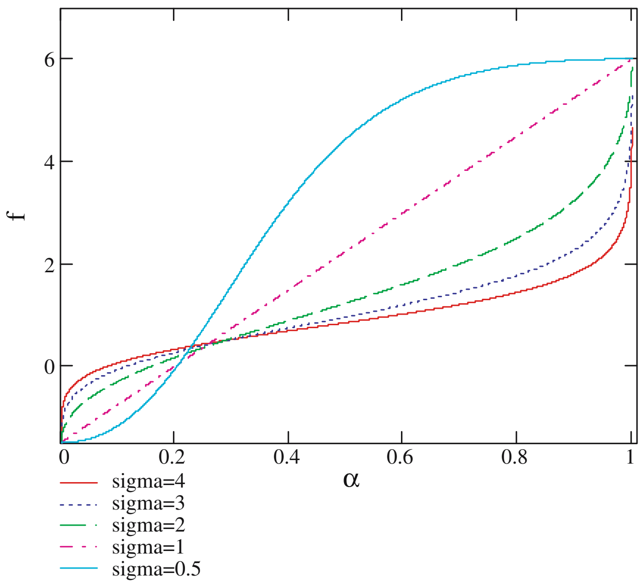

Fig. 3 Devaluation risk: share of assets held in foreign currency

probability. (3) Higher values of σ reduce the amount of foreign currency desired at each value of α such that f is positive (in our example the threshold value of α is about 35%); on the other hand, for values of α below the threshold, increasing σ raises the amount of foreign currency desired; (4) The f-schedules become flatter as σ increases and then rise rapidly to approach f_1 as the probability of crisis approaches unity; (5) An increase in the magnitude of the devaluation (a lower value of e) raises f at each probability and interest rate combination.

4.3 Interest rate defense

Demand for foreign currency in the presence of devaluation risk is positive if domestic real interest rates are "low". As in the logarithmic case, f^* is positive only if R is below a threshold that depends on the parameters (e, α, σ). For the currency demand (22) generated by CRRA preferences, f^* is positive if and only if

$$R < \bar{R} \equiv \frac{\alpha e^{-1} + (1-\alpha)\rho^{-\sigma}}{\alpha + (1-\alpha)\rho^{-\sigma}} > 1. \qquad (24)$$

Equation (24) illustrates an important difference between inconvertibility and devaluation risk. It will be recalled from Section 2 that the currency substitution due to convertibility risk cannot be successfully countered with interest rate hikes if the crisis probability is high. The situation is quite different if currency substitution is due to devaluation risk. Here an interest rate defense can be quite successful. All that is required to extinguish demand for foreign currency is to raise

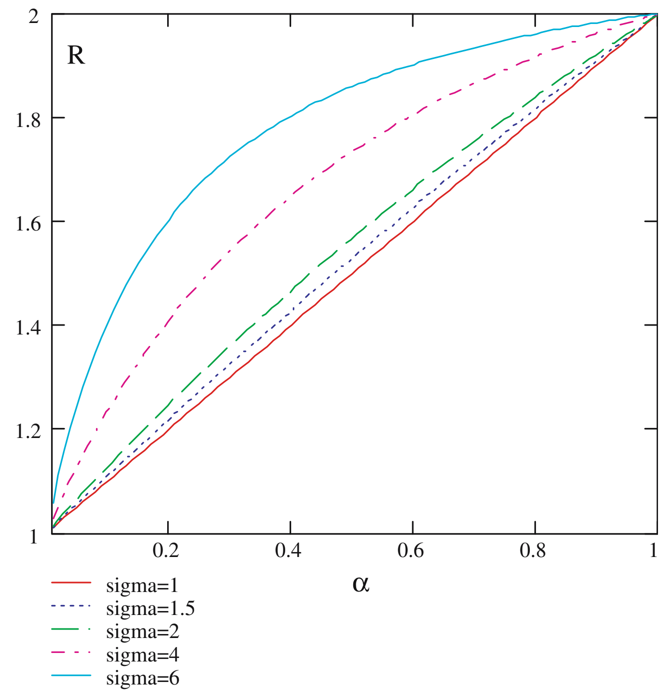

Fig. 4 Threshold interest rate required for interest rate defense

domestic real interest rates to the threshold given in (24). This threshold depends on the characteristics of the crisis and of preferences (e, α, σ). Worsening crisis conditions require a higher interest rate (at each value of σ) to stop and reverse currency flight. In Figure 4 the threshold interest rate is plotted against the crisis probability α for various values of σ (these calculations also assume e=0.6). It is also clear that, given α, higher values of σ raise the threshold interest rate.

This discussion can be summarized as follows. In the face of convertibility risk, demand for foreign currency assets remains positive regardless of the level of domestic real interest rates. This is due to the presence of the Inada condition on good y: agents would suffer large utility losses if they found themselves in the inconvertibility state with no precautionary foreign currency balances and no access to the spot foreign exchange market. Under devaluation risk, on the other hand, an interest rate defense is much more potent because access to the foreign exchange market is not an issue and, in light of assured access to the market a t+1, agents' calculations are driven entirely by rate-of-return considerations.

4.4 Interest rate defense and the magnitude of devaluation

Shifts in the public's perceptions of the features of the expected devaluation are all-important in deciding how large a hike in interest rates is required to defend the currency. There is clearly a tradeoff between e and $\bar{R}$: a larger devaluation

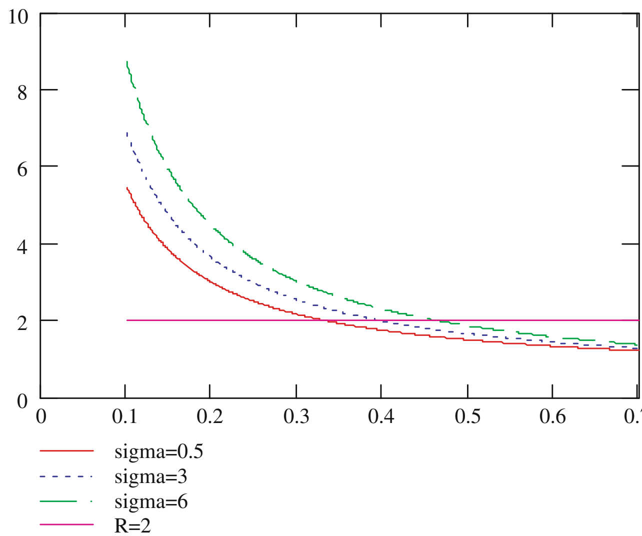

Fig. 5 The tradeoff between interest rate defense and devaluation

requires a higher threshold interest rate to contain pressures on the domestic currency (expression (24) and Fig. 5). Assuming a 50% crisis probability, a 30% devaluation requires interest rates between 21 and 27% to induce domestic asset holders not to switch into dollars. If the expected devaluation is 60%, interest rates between 71% and 124% are required to prevent currency substitution. And if the expected devaluation rises to 80%, real interest rates of between 185 and 380% would be needed.

5 Time series demand for money

5.1 Estimation strategy

The estimation strategy is to extend the usual equation for money demand to encompass variables that are linked to the likelihood of crisis. The modern approach to the estimation of money demand functions is to use cointegration methods, which take into account the stationarity properties of the variables and which separate out the long-run from the short-run effects. This strategy has an important additional advantage: the effect of crises on money demand is most likely to be quantitatively important over the short-run, since a country (at least, a country like Korea, which has enjoyed relatively good macroeconomic performance over the past 30 years) will generally not be in a crisis or close to a crisis. Hence, the estimation strategy needs to focus separately on short-run impact effects if it is to have any chance to separate out the impact of the crisis on money demand.

Equation (26) below focuses on the long-run relationship, as it estimates the link between the *levels* of money demand and the *levels* of the explanatory variables. In this setup, the coefficients give the estimated long-run impact of a change in the explanatory variables on money demand. Equation (27) focuses on the short-run relationship, as it estimates the link between the *changes* of money demand and the *changes* of the explanatory variables. In this setup, the coefficients give the estimated short-run impact. The link between the short- and long-runs is captured by the inclusion of the "cointegration" variable in the short-run equation, which allows for a feedback between a disequilibrium today on short-run money demand.

The starting point of the empirical investigation is to select the candidate explanatory variables and to subject them to stationarity tests. The variable to be explained is real money demand, and the potential explanatory variables comprise real output, interest rates and inflation (these variables are standard), plus the exchange rate and reserves (the new variables that are thought to be linked to the probability that domestic currency will become inconvertible).[9] [10] Standard augmented Dickey-Fuller (ADF) tests are performed, confirming that the variables are non-stationary, and that they are integrated of order one (their differences are stationary).[11] Hence, a cointegration framework is the statistically appropriate way to estimate the money demand equation. The Appendix presents more detail on the variable definitions and on the stationarity tests.

Given the focus of the study on the short-run, a two-step estimation procedure is selected, although the longest possible sample is included in the estimation (monthly data starting in February 1970 and ending in September 2000). The two-step Engle–Granger estimation procedure is followed here, as it allows us to focus on the short-run, and because of its simplicity, allowing for instance for an easy implementation of an instrumental variables estimation technique.[12] One important complication is the possible endogeneity of exchange rates – they would in general be affected by money demand – and the link of reserves to money through the central bank balance sheet identity (discussed in footnote 7). To ameliorate the impact of endogeneity on the estimated coefficients, an instrumental variables

[9] One issue which is not entirely clear from theoretical framework is the monetary aggregate that would be appropriate to use in the empirical tests. Clearly, the fear of inconvertibility could in principle spill over to longer-maturity components of money, if they were liquid enough, which would argue for using a broad monetary aggregate. We ran our regressions both on narrow and broad definitions of money. While both definitions were influenced by the "crisis" variables, the residuals for narrow money were larger, presumably because that equation was not able to account satisfactorily for shifts between components of money. As these shifts are not the main objective of this paper, the analysis is focused on broad money (the sum of money and quasi money, as defined in the IFS database, excluding foreign currency deposits – series BBAA2113, obtained from the Bank of Korea web site, http://www.bok.or.kr). The national (Bank of Korea) definition of broad money is consistent with the IFS definition.

[10] Another qualification concerns the interpretation of inconvertibility. If the exchange rate is allowed to float, movements in the exchange rate capture return (akin to the interest rate) rather than inconvertibility considerations. The two versions of the theoretical model earlier presented capture these two different possibilities. The empirical equations here do not distinguish cleanly between the two complementary motivations.

[11] Noting that the fact that inflation is found to be integrated of order one (a result also sometimes found for other countries) implies that the CPI price index is integrated of order two. To keep the estimated equations balanced in terms of the order of integration between the left-hand and the right-hand sides implies that we use inflation in the long-run equation, and the change in inflation in the short-run equation.

[12] It remains for future work to implement more sophisticated estimation methods, such as the method due to Johanssen.

estimation technique was used (2SLS), using as instruments for the exchange rate and for reserves lagged exchange rate and lagged reserves.[13]

5.2 Econometric results

After some experimentation, the following long-run and short-run specifications were respectively selected:

$$\log\left(\frac{h_t}{p_t}\right) = 7.45 + 0.87\log(y_t) - 0.01 i_t + 0.007\pi_t + 0.02\log(e_t) + 0.10\frac{R_t}{M_t} + u_t \qquad (25)$$

and

$$\Delta\log\left(\frac{h_t}{p_t}\right) = 0.02 + \text{seasonals} - 0.018 u_{t-1} + 0.1\Delta\log\left(\frac{h_{t-1}}{p_{t-1}}\right) + 0.09\Delta\log(y_t) - 0.0003\Delta i_t - 0.004\Delta\pi_t - 0.11\Delta\log(e_t) + 0.01\Delta\left(\frac{R_t}{M_t}\right) + v_t. \qquad (26)$$

In addition to symbols already defined, y_t denotes real output, i_t the interest rate, e_t the (average period) exchange rate in won per dollar, R_t/M_t reserves divided by imports, u_t the estimated residuals from the long-run equation, and Δ the difference operator, and *seasonals* a set of monthly seasonal dummies (not shown here to conserve space). In terms of statistical significance, all variables except inflation and the exchange rate are found to be statistically significant at the 5% level in the long-run equation, and all variables except interest rates are found to be statistically significant at the 5% level in the short-run equation.

The estimated equations perform reasonably well when examined against standard benchmarks, which is striking considering that no allowance was made for possible breaks in the relationship and that different components of money are not modeled separately.[14] The long-run equation has an $\bar{R}^2$close to 0.99, and the short-run equation has an $\bar{R}^2$ of 0.45, with a D.W. statistic of 2.05. Perhaps more impressive is the ability of the estimated equation to produce forecasts of real money that track actual real money even during December 1997, the month when the crisis hit in earnest (see Fig. 6). Finally, the "cointegration" residual u_t is found using

[13] This solution has its costs, mainly that one uses proxies that by necessity are not as informative as the actual variables themselves. To see how significant this loss of information is, the regressions were run both with and without the use of instruments. In the event, the regression coefficients for the exchange rate and reserves were fairly close between the two sets of regressions, and the main results from the counterfactual simulation were not significantly affected (although, as expected, the t-statistics are generally lower for the 2SLS estimates). For concreteness, the results reported in the paper focus on the 2SLS estimated long-run equation and the OLS estimated short-run equation.

[14] for example the macroeconomic model used by the Bank of Korea has several different equations separately explaining various components of broad money (Kim 1998).

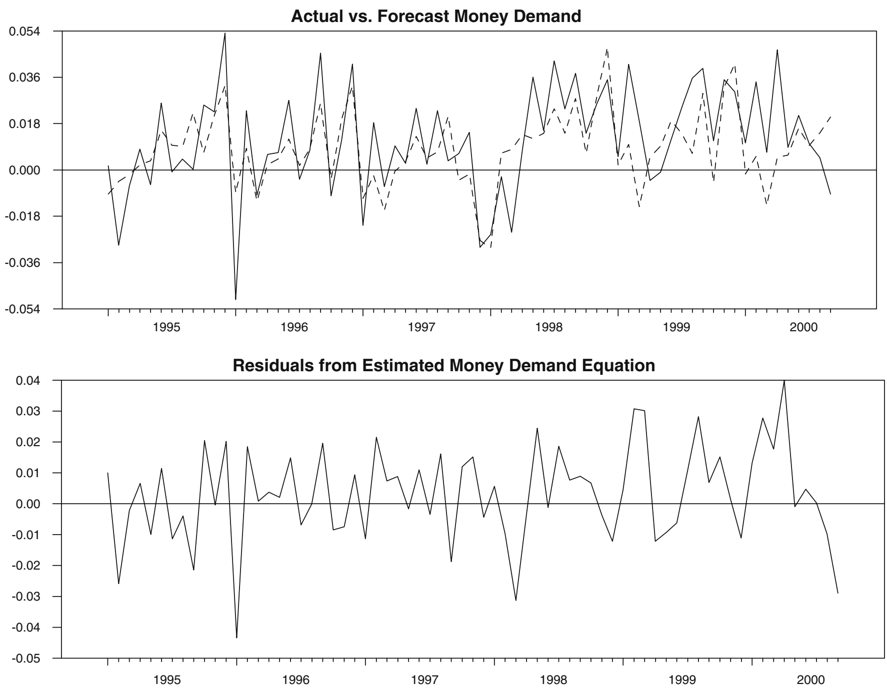

Fig. 6 Money demand equation (in changes; logarithmic scale)

the ADF test to be stationary, which further validates the use of the cointegration framework.[15]

The estimated coefficients are in accord with theoretical expectations, including for the new theoretical framework that incorporates the effect of inconvertibility. Over the long-run, the demand for real money is driven positively by real output and negatively by nominal interest rates, while inflation turns out to be insignificant. Since the inconvertibility framework does not provide clear predictions over the long-run relationship between risk variables (here, proxied by exchange rate and reserves) and real money, we do not attempt to interpret their coefficients in the long-run equation.

Over the short run, real money demand adjusts sluggishly toward its long-run equilibrium. The coefficient on the u_{t-1} term in equation (8) shows that money demand adjusts by 1.8% per month in response to disequilibrium (about 24% of the disequilibrium disappears over the course of 1 year, and 50% after 23 months). From the point of view of this paper, the key implication is that one can focus mainly on the short-run impact multipliers from the exchange rate and reserve variables onto money demand (which is very helpful for the counterfactual simulations), as any long-run disequilibrium effects would be negligibly small at the one-month frequency.

[15] The ADF statistic (using the same assumptions as described in the Annex for the other variables) is -3.1, with a critical value for a test at a 5% significance level of -2.88.

The main finding is that the "crisis" variables have the predicted impact on real money demand. As the short-run equation shows, a depreciation of the exchange rate and a loss of reserves both act to depress the demand for money, and the result is statistically significant. The next section examines the quantitative significance of this effect more closely, and provides a comparison with an alternative estimate based on the cross-sectional approach in the previous section.

5.3 A Counterfactual simulation

Armed with the estimated money demand equations, it is possible to produce an ex post estimate of the impact of the crisis. The money stock fell by about 3% in December 1997 and a further 2.5% in January 1998. The model predicted a fall of 2.0 and 2.6%, respectively, a good prediction for what was an unusual period. One implication is that the model did not explain about 1% point of the decline in money demand (this could have happened for various reasons, including the possibility that the proxy variables used to capture the risk of inconvertibility were less than perfectly correlated with the information set available to households at that time). Nevertheless, the key question is how much of what the model explains is due to the "crisis" variables.

A counterfactual simulation reveals that the "crisis" variables (exchange rates and interest rates) helped explain an important part of the reduction in money demand during December 1997. As already mentioned, the key question is how much of the model-predicted fall in demand can be explained by the "crisis" variables. We (counterfactually) set the changes in the exchange rate and reserves to zero during December 1997, and recomputed the model forecasts. The difference between these new, conditional, forecasts and the earlier forecasts is the model's estimated impact of the crisis variables onto money demand. The model counterfactually forecasts that the demand for money would actually have *increased* (which is reasonable, as this would have been expected in line with the usual seasonal pattern) by 2.0% , a difference of 4.0% points versus the model's unconditional forecast (and 5.0% points versus the growth in the actual money stock during December 1997).

Using real money at end-November 1997 as a base, the counterfactual simulation implies that the inconvertibility channel from the crisis to the demand for money translated into a loss of reserves of between \$6–7.5 billion.[16] The calculation is performed by using the end-of-period November 1997 exchange rate (1,163.8 won per dollar) to calculate broad money in dollars (\$150 billion). Then, one applies the estimated effect (4–5%) of the crisis variables on money demand to this number. To put the estimated impact on reserves in perspective, it represented almost 30% of foreign exchange reserves (excluding gold) measured as of end-November 1997 (\$24.4 billion). Evidence supporting these estimates is provided in Figure 7 showing Foreign Currency Deposits in Korean banks.

One important problem discovered after the initial impact of the crisis is that reserves were mismeasured, with truly useable reserves being much lower than

[16] The effect could be somewhat larger if the value of real money then were translated into today's money (between end-November 1997 and the end of the sample period in September 2000 the CPI index rose by about 10%).

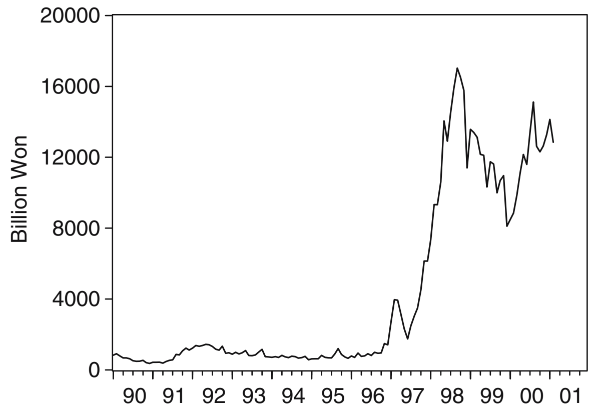

Fig. 7 Foreign currency deposits

those reported publicly at that time. This has two distinct sets of implications for the analysis in this paper. One is whether the mismeasurement would influence the estimated coefficients, and the other is in assessing the importance of the inconvertibility effect on money demand. As to the former, it is in all likelihood not an important problem, because people would be reacting to the data that they had available at the time of the crisis. It therefore makes sense to use data that is closest to what would have been observable at the time. As to the latter implication, however, it is important to have an understanding of the true extent of the deterioration in reserves.

Given that useable reserves, excluding the emergency IMF assistance, declined to practically zero at end-1997, it is concluded that the impact of the possible loss of convertibility on reserves was a significant, but not the most important factor. Estimating the decline in reserves in the last few months of 1997 to be approximately \$24 billion, of which 30% was due to the inconvertibility effect on money demand, it is concluded that 70% of the loss of reserves was due to other factors. Without performing a detailed analysis of those other factors, it is not possible to conclude with precision how important these other factors might be. This could be a topic of future research endeavoring to isolate further the other channels by which crises influence reserves. However, it is known that much of the outflow from Korea during the crisis was linked to the inability to roll over short-term debt, as creditors became unwilling to refinance their exposure. Tentatively, therefore, one can conclude that the short-term debt vulnerability indicator may have been of more significance than the inconvertibility channel.

In terms of the external vulnerability indicators, the analysis in this paper implies that Korean reserves have recovered to levels that are adequate to cover plausible shocks to money demand. Assuming that the shock from the 1997 crisis to money demand was at the high end (representing a kind of natural "stress test"), reserves should cover at least 5% of broad money. In fact, the reserve level of \$96 billion at end-2000 covers 11%. This should be contrasted with the inadequate level at end-1997, when useable reserves, inclusive of the emergency support from the Fund, were at 2.2% of broad money.

An alternative approach using cross-sectional data (available from the authors) finds a larger impact on money demand and reserves from a potential lack of convertibility. The main finding in the preceding section was that long run money demand was 10.3% lower for countries with permanently inconvertible currencies. This effect is between 2.1–2.6 times larger than what was estimated using the Korean-specific time series money demand function. The finding in the cross section analysis would have meant that reserves would have fallen much more on the strength of the inconvertibility channel alone.

It seems unlikely that the higher estimate for the impact on reserves is applicable in the majority of the cases. Given the method of estimation, it seems that only full and permanent inconvertibility would result in a reduction in money demand of the full 10.3% (so that amount can be viewed, in general, as an overestimate). More likely, households ascribe some probability to the possibility of inconvertibility that is less than 100%. Even given the severity of the crisis in Korea, it is not plausible that households came to expect full (not to mention permanent) inconvertibility. Under these circumstances, the estimate that money demand fell by between 4–5% points seems a more reasonable one.

6 Concluding remarks

This paper presents a theoretical and empirical analysis of the impact of anticipated and actual inconvertibility on domestic money demand and reserves. Using a simple model featuring multiple currencies we show that the prospect of inconvertibility gives rise to a precautionary motive for foreign exchange. Whereas in normal times the domestic currency is freely convertible at a fixed exchange rate, the threat of loss of convertibility – as might occur during a crisis – raises demand for foreign currency assets at the expense of the demand for domestic money. The central bank could respond by raising domestic interest rates, which would raise domestic money demand through a direct substitution effect. However, an interest rate defense of the currency is not effective if there is a significant risk of inconvertibility. Instead, convertibility could be maintained by abandoning the currency peg, in which case the required depreciation of the currency would be dictated by the elasticity of supply of foreign currency with respect to the price. However, if the central bank is not willing to allow the exchange rate to fluctuate enough to elicit the needed supply (or dampen the demand sufficiently) then the only options left are initiating adjustment via some combination of interest rates, expenditure restriction, devaluation, or trying to arrange financing via the IMF or other borrowing.

In the empirical part of the paper, we first examine cross section differences in the demand for money when convertibility is impaired. Next we use time series cointegration techniques to estimate the impact of the prospect of inconvertibility on money demand during the recent currency crisis in Korea. Our preliminary estimates of the effect of the foreign crisis on money demand and reserves for Korea show that the impact of inconvertibility is significant. The loss of reserves attributed to inconvertibility was of the order of $7 billion, or about one-third the reserves available at the time. This effect is separate from the reserve loss attributed to the non-rolling over of short-term capital driven by the over-leveraging of Korean corporations.

This study offers some insights for policies designed to contain external vulnerability and particularly for reserves. This effect is smaller than our cross section estimate. Of course the conclusions are tentative pending further research.

- At times of crisis, money demand will generally fall as households perceive the risk of domestic currency becoming inconvertible as rising. This intuitive theoretical prediction is born out by the empirical time series analysis carried out for the case of Korea in this paper.
- The negative impact of a crisis on money demand, and the attendant negative spillovers to international reserve holdings, can be significant but, for countries whose problems are perceived to be temporary, and that have a reasonable amount of initial reserves, manageable. Korea's current reserves, when compared with broad money, would more than cover a shock to money demand equivalent to that sustained during the 1997 crisis.
- From the usual indicators of external vulnerability, the analysis in this paper finds that the reserves-to-broad money ratio is an important indicator. At least for the case of Korea, one can tentatively say that the reserves-to-short term debt (measured by residual maturity) variable may have been quantitatively more important. Further theoretical and empirical work needs to be done, however, to conclusively rank the importance of alternative indicators of vulnerability.

Appendix A. data sources

The data used are all collected from the Fund's International Financial Statistics (IFS) database, and are monthly series for the period February 1970 to September 2000.

The key definitions used include:

- Real broad money is the end-of-period sum of money and quasi money (minus foreign currency deposits) deflated by the CPI index, seasonally unadjusted.
- Real output is the industrial production index, seasonally adjusted.
- The interest rate is the monthly yield on deposits longer than 1 year.
- Reserves is end-of-period foreign exchange reserves excluding gold measured in dollars, divided by imports also measured in dollars.
- The exchange rate is the monthly average market rate, measured in won per US dollar. For converting money stocks to dollars the end-of-period rate is used instead.

To extend the sample back to 1970, it was necessary to use the aforementioned interest rate (some alternative series started much later). This entailed some loss of information as there were periods over which that rate did not change (there were periods over which it apparently was changed only infrequently). There was no definition of quasi money in the IFS database that was seasonally adjusted, and there was no definition of industrial production that was seasonally unadjusted. To account for this discrepancy, the short-run regression equation includes seasonal dummies.

The tests of variable stationarity yielded the following results:

One notable result, often found also in other country cases, is that inflation is integrated of order one (hence, the difference of inflation is stationary). This

Table 1 Augumented Dickey-Fuller (DF) Tests

Variable	Levels	Difference	Conclusion
Broad money divided by CPI	0.24	−3.57	The variable is integrated of order 1
Output	−1.62	−4.18	The variable is integrated of order 1
Interest Rate	−2.73	−4.86	The variable is integrated of order 1
Inflation Rate	−2.68	−7.34	The variable is integrated of order 1
Exchange Rate	−1.65	−5.13	The variable is integrated of order 1
Reserves-to-Imports Ratio	−0.75	−3.87	The variable is integrated of order 1

Performed assuming 12 lags and including a constant and no trend, and assuming that the constant equals zero under the null hypothesis
Note: The 5% critical value for the ADF test is −2.88 (James Hamilton Time Series Econometrics, 1994, Table B.6, case 2)

implies that the CPI is integrated of order two. This explains why in the long run equation it is inflation that is used (to keep the orders of integration commensurate between the left-hand and the right-hand sides of the equation) and why it is that in the short-run equation it is the difference in inflation that is used.

Appendix B. the optimal currency portfolio with devaluation risk

This section derives the optimal foreign-currency portfolio in the presence of devaluation risk for the CRRA class of preferences. Consumer demands in state $i = 1, 2$ are

$$x^i = \frac{1}{e^i + \left(\delta e^i\right)^{\frac{1}{\sigma}}}\Big[f + e^i(W - f)R\Big];$$

$$y^i = \frac{\left(\delta e^i\right)^{1/\sigma}}{e^i + \left(\delta e^i\right)^{1/\sigma}}\Big[f + e^i(W - f)R\Big]. \tag{27}$$

These schedules are positive in the f-interval $f_0 \leqslant f \leqslant f_1$, where $f_0 \equiv -eR/(1 - eR)\ W$, $f_1 \equiv R/(R-1)W$. Assuming $f_0 \leqslant f \leqslant f_1$, indirect utility in state i, U^i, is proportional to real wealth in that state raised to the power $1 - \sigma$:

$$U^i = \frac{1}{1-\sigma} \cdot \frac{1}{e^i} \cdot \left[e^i + \left(\delta e^i\right)^{1/\sigma}\right]^{\sigma} \cdot \Big[f + e^i(W - f)R\Big]^{1-\sigma}. \tag{28}$$

Expected utility and its first and second derivatives may be written as function of f as follows:

$$\begin{aligned} EU = (1-\alpha)&\frac{1}{1-\sigma}\left[1 + \delta^{1/\sigma}\right]^{\sigma}[f + R(W - f)]^{1-\sigma} \\ &+\alpha\frac{1}{1-\sigma}\left[e + (\delta e)^{1/\sigma}\right]^{\sigma} e^{-1}[f + eR(W - f)]^{1-\sigma}; \end{aligned}$$

$$\begin{aligned} EU'(f) = (1-\alpha)&\left[1 + \delta^{1/\sigma}\right]^{\sigma}[f + R(W - f)]^{-\sigma}[1 - R] \\ &+\alpha\left[e + (\delta e)^{1/\sigma}\right]^{\sigma} e^{-1}[f + eR(W - f)]^{-\sigma}[1 - eR]; \end{aligned}$$

and

$$EU''f = (1-\alpha)\left[1+\delta^{1/\sigma}\right]^{\sigma}(-\sigma)[f+R(W-f)]^{-\sigma-1}[1-R]^2$$
$$+\alpha\left[e+(\delta e)^{1/\sigma}\right]^{\sigma}(-\sigma)[f+eR(W-f)]^{-\sigma-1}e^{-1}[1-eR]^2.$$

$EU''(f) < 0$ if and only if $\sigma > 0$. In this case there is a unique maximum f^*given by

$$(1-\alpha)\left[1+\delta^{1/\sigma}\right]^{\sigma}[f+R(W-f)]^{-\sigma}[R-1]$$
$$=\alpha\left[e+(\delta e)^{1/\sigma}\right]^{\sigma}[f+eR(W-f)]^{-\sigma}e^{-1}[1-eR].$$

Rearranging terms and simplifying yields the following:

$$\left[\frac{f+R(W-f)}{f+eR(W-f)}\right]^{-\sigma} = \frac{\alpha}{1-\alpha}\left[\frac{e+(\delta e)^{1/\sigma}}{1+\delta^{1/\sigma}}\right]^{\sigma}\frac{e^{-1}-R}{R-1}$$
$$\Leftrightarrow \frac{f+R(W-f)}{f+eR(W-f)} = \left(\frac{\alpha}{1-\alpha}\left[\frac{e+(\delta e)^{1/\sigma}}{1+\delta^{1/\sigma}}\right]^{\sigma}\frac{e^{-1}-R}{R-1}\right)^{-1/\sigma}. \tag{29}$$

Define the parameter $\rho > 0$ by

$$\rho = \frac{1+\delta^{\frac{1}{\sigma}}e^{\frac{1-\sigma}{\sigma}}}{1+\delta^{\frac{1}{\sigma}}}. \tag{30}$$

The value of ρ depends on the preference parameter σ and the exchange rate in the devaluation state e. $\rho = 1$ if $\sigma = 1$, while $\rho > 1$ if $\sigma > 1$ and $e < 1$. From equations (29) and (30), the optimal portfolio is

$$f^* = RW\frac{\rho\left[\frac{\alpha(e^{-1}-R)}{(1-\alpha)(R-1)}\right]^{\frac{1}{\sigma}} - 1}{\rho\left[\frac{\alpha(e^{-1}-R)}{(1-\alpha)(R-1)}\right]^{\frac{1}{\sigma}}(R-1)+\left[e^{-1}-R\right]}. \tag{31}$$

As can be seen from (31), f depends on the difference (actually the ratio) of the expected returns on foreign and domestic currency assets $\alpha(e^{-1}-R)+(1-\alpha)(1-R)$.

In the log case $\sigma = \rho = 1$, and (31) reduces to $f^* \equiv WR\left[\frac{\alpha}{R-1} - \frac{1-\alpha}{e^{-1}-R}\right]$.

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