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## Financial crises, capital liquidation and the demand for international reserves

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**Financial Crises, Capital Liquidation  
and the Demand for  
International Reserves**

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# Financial Crises, Capital Liquidation and the Demand for International Reserves

Alex Mourmouras and Steven H. Russell

Preliminary and Incomplete

## Abstract

We study a simple neoclassical model of investment in a developing country, modified to allow for long-term projects and short-term debt. Early signals indicating low productivity of investment may lead creditors to call loans in early. In such a crisis, firms protected by limited liability default and liquidate capital, even though they do so at a loss (a “fire sale”). We show that short-term debt financing is beneficial in good (normal) times: when there is no adverse signal, and thus no need to liquidate capital, investment, the capital-labor ratio, wages and *ex post* worker utility are all higher than they would be if liquidation were not possible or was prohibited. Capital liquidation exacerbates the effects of negative shocks by lowering the capital-labor ratio and lowering wages in bad times (crises). Capital liquidation raises the variability of wages and hurts workers who cannot insure against wage income (this seems plausible in emerging market economies). Accumulating a stock of international reserves to be used during or after a crisis can mitigate the adverse effects of capital liquidation on wage variability and worker welfare.

## I. INTRODUCTION

At the heart of the financial crises that enveloped many developing countries in the 1990s were dramatic reconsiderations of the profitability of private investment. Once they assessed future profits realistically, domestic and foreign investors scrambled for the exits. Faced with sudden stops in the flows of foreign capital they had come to depend on to finance long-term investment projects, emerging market countries often resorted to costly fire sales of domestic assets, disrupting investment and hurting economic growth.

The ensuing recessions were short-lived but deep in many cases, and unemployment and inflation rose significantly. Real output declines combined with steep exchange rate depreciations to reduce these countries' output measured in international values (i.e., in US dollars at market exchange rates), which raised the burden of foreign currency debts. These were clearly extraordinary events—especially countries that enjoyed low public debts and deficits and had been growth miracles. They traumatized the affected countries and led them to reevaluate the size of the fiscal and financial cushions they needed to protect themselves. Academics concurred. In an influential early paper, Martin Feldstein (1998) argued that countries with open capital accounts needed to self-protect themselves. As Table 1 shows, many of the countries afflicted by crises have raised substantially their stocks of official international reserves in relation to GDP.

The debate has now swung in the opposite direction, with many observers questioning the wisdom of large reserves holdings. In this paper, we address this question using a simple neoclassical model of investment, modified to allow for long-term investment projects, capital liquidation and short-term foreign currency debt. The model is in the tradition of Diamond and Dybvig's (1983) analysis and its extension to the open economy by Chang and Velasco (1998). It also shares with Aizenman and Lee (2004) the property that domestic distortions (tax distortions in their case, incomplete markets in ours) influence the optimal size of international reserves. Unlike these treatments, however, our model assumes that output is produced using inputs of capital and labor, allowing us to calibrate parameters and study quantitatively the consequences of crises and the effect of reserves policy on worker welfare. In this sense, it is closer to the work of Jeanne and Ranciere (2005), although ours is not a fully articulated growth model.

The model is intended as a description of infrequent but severe shocks that cause creditors to call loans in early and developing country firms to liquidate capital. The economy evolves over three periods, which is the minimum needed to produce disruptions to financial plans that spill over to the real economy. There are three modifications to standard analysis. First, early signals warn workers, investors, and governments about future shocks to total factor productivity (TFP). The TFP shocks model in a stylized way a variety of large shocks that affect investment returns in many developing countries. The signal captures in a convenient

way the reality that crises are triggered by the arrival of unfavorable information about economic and political developments. Second, lenders call in loans early once bad signals are observed, and firms subject to limited liability default and liquidate capital in a fire sale to pay off loans (Krugman (1999)) and others have emphasized the importance of these fire sales). In the model, the option of liquidation is not exercised unless the adverse shock is “large” and “rare.” Third, workers do not have access to wage insurance, an assumption that seems natural in many developing countries where unemployment insurance and safety nets are not well developed.

We show that liquidation and short-term debt are beneficial in good times. Firms raise investment and workers benefit from higher capital intensity and enjoy higher real wages relative to an equilibrium in which fire sales are not possible. However, liquidation also generates more instability in the relatively rare circumstances in which it is exercised—i.e. when the country is hit by relatively large shocks. Liquidation lowers the capital-labor ratio. Because workers in many emerging markets cannot insure against wage volatility, and the variability of wages rises when firms liquidate capital, workers’ expected utility declines. This result is likely to be strengthened if labor market frictions prohibit rapid wage adjustments, in which case the economy would also experience higher unemployment.

Model calibrations indicate that capital liquidation can have a potentially large and harmful effect on worker welfare for a range of assumptions regarding attitude to risk commonly assumed in the literature. The increased variability of wages associated with crises costs workers something like three percent of income if the coefficient of relative risk aversion (CRRA) is two, which represents mild aversion to risk. If relative risk aversion coefficient doubles to four, indicating strong but still reasonable aversion to risk, workers must receive compensation of over 10 percent of income.<sup>1</sup>

To contain the welfare costs of crises, policy needs to cushion the effects of liquidation on capital accumulation. A first-best intervention would target the underlying distortion responsible for the large loss in welfare. Since the fundamental problem is a failure of markets to provide workers wage insurance, the preferred solution would be for government to encourage the development of such markets or make available such insurance itself. But the implementation of comprehensive social insurance and social safety nets requires new legislation and institutions that cannot be put in place quickly. When the size of the output decline in the Asian countries affected by the 1997-99 crisis became apparent, for instance, IMF-supported programs strove to expand social safety nets and raise budget deficit ceilings in order to make room for automatic stabilizers to work and for additional, discretionary social spending. In many cases, fiscal outcomes in these countries were tighter than

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<sup>1</sup> This approach to measuring the welfare impact of income fluctuations was pioneered by Lucas (1987) and is now standard in the Real Business Cycle literature.

envisaged in the revised programs because governments could not quickly put into operation the additional fiscal stimulus (Lane and Tsikata (1999), p. 62.)

In the absence of first-best policies, or perhaps in combination with efforts to provide them, it is necessary to consider indirect interventions. One such approach was tried with some success in Chile. It involves taxation of capital inflows through the imposition of reserve requirements on short-term, hot money flows. The reserve requirement both throws sand in the wheels of international capital markets<sup>2</sup> and enables the authorities to build a stock of international reserves that they can employ in a crisis to limit the severity of the capital liquidation. Empirical evidence indicates that in developing countries with large foreign currency debts since 1980, central banks have responded to sudden stops of capital inflows by releasing significant quantities of international reserves, regardless of the exchange rate regime (Calvo, NBER WP 12788, 2006, Table 1, pp. 4-5). We show that this policy can succeed in raising worker welfare all the way to the no-liquidation level. This is consistent with well-known results in public finance—that introducing a second distortion can offset the effects of the first.

The analysis is simple and provides stark answers to the question of how large a stock of international reserves a country needs. Because the damage to welfare can be high if the country cannot defend itself against demands for early liquidation, the stock of international reserves it must keep can be very high in relation to GDP—as high as observed in recent years under plausible parameterizations. But because this war chest is unused most of the time—it is deployed only when relatively infrequent but severe crises hit—it is understandable that observers may question the wisdom of maintaining them.

## II. INVESTMENT WITH A LIQUIDATION OPTION

Consider a small open economy that lasts three periods, corresponding to the installation of capital, the arrival of the signal, and production. Firms are competitive and operate under constant returns to scale. They employ a Cobb-Douglas technology in labor and capital to produce a single good whose world price is fixed. Investment is put in place in the installation period and comes to fruition two periods later. The return to investment can be high or low, depending on the value of TFP in the production period. In the intermediate period, workers, domestic and foreign financial and nonfinancial firms and the government

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<sup>2</sup> This policy is related to Tobin's proposal to tax foreign exchange flows, originally made in 1972. See Tobin (1979). For a skeptical review, see Garber and Taylor (1995). It is also related to proposals for imposing reserve requirements on inflows. For a sympathetic view, see Williamson (2005, pp. 97-98). But whereas most proposals are for unremunerated reserve requirements on inflows, we analyze the welfare effects of reserve requirements on debt flows that pay the world rate of interest.

observe a public signal about the size of TFP.<sup>3</sup> Either productivity will be high,  $Az_1$ , with probability  $1-\theta$ , or it will be low,  $Az_2$ , with probability  $\theta$ , where  $A>0$  and  $z_1 > z_2 >0$ . We think of this adverse productivity shock as a shortcut that captures the effects of economic, institutional and political shocks that can affect developing countries.

When investment is initiated, a unit of capital can be purchased with one unit of the consumption good. Capital depreciates at rate  $\delta$  over the two periods between installation and production. Firms have the option of interrupting investment during the intermediate period in response to adverse signals. A unit of capital “in process” can be sold in the world market for scrap at a price  $x<1$ . When the adverse shock is realized, firms protected by limited liability declare bankruptcy. In bankruptcy, firms pay wages first and hand over any remaining revenues to their lenders. Since firms must earn zero expected profits in equilibrium, the only return-rate pair choices consistent with equilibrium are choices that produce zero profits in both states.

Firms raise investment funds from costless and competitive domestic banks. These banks, in turn, fund themselves from risk-neutral lenders in the world market. If the real rate of interest in the world market is  $\bar{r} > 0$  per period, then the gross two-period real rate is  $\bar{R} \equiv (1 + \bar{r})^2$ . Firms can obtain funding so long as uncovered interest parity (UIP) holds:

$$(1 - \theta)R + \theta d = \bar{R}. \quad (1)$$

UIP ensures that the banks and their foreign investors are compensated for low rates of return in bad TFP states, denoted  $d$ , through higher rates of return, denoted  $R$ , in goods states.

There are  $\bar{L} = 1$  domestic workers who supply a unit of labor each during the production period in exchange for a wage  $w$ . Wages are either high,  $w=w_1$  with probability  $1-\theta$ , or low,  $w=w_2$ , with probability  $\theta$ . We assume that workers cannot insure themselves against fluctuations in wage income. Their utility function is

$$E\{u(w)\} = (1 - \theta)u(w_1) + \theta u(w_2). \quad (2)$$

In the computational analysis, we will use the Constant Relative Risk Aversion (CRRA) family of utility functions, given by  $u(w)=(w^{1-\gamma}-1)/(1-\gamma)$ ,  $\gamma>0$ , which includes logarithmic preferences as a special case  $\gamma=1$ .

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<sup>3</sup> This assumption is sufficient for us to make our main point in an analytically tractable manner but is far from innocuous. Noise in the signal affects borrowing, capital intensity, wages and welfare.



A firm that borrows and invests  $K$  units of capital during the installation period has the option of liquidating a fraction  $\psi$  of this capital a period later. Letting  $L_i$  be labor hired in state  $i=1,2$ , we have  $k_1 = K / L_1$ ,  $k_2 = (1-\psi)K / L_2$  and we can write output as

$$Y = \begin{cases} Az_1 K^\alpha L_1^{1-\alpha} = Az_1 k_1^\alpha L_1 & \text{w.p. } 1-\theta \\ Az_2 (1-\psi)^\alpha K^\alpha L_2^{1-\alpha} = Az_2 k_2^\alpha L_2 & \text{w.p. } \theta \end{cases}, \quad (3)$$

Firms select  $\{L_1, L_2, K, \psi\}$  to maximize expected profit  $E\{\Pi\} = (1-\theta)\Pi_1 + \theta\Pi_2$ , where

$$\Pi_1 = Az_1 K^\alpha L_1^{1-\alpha} + (1-\delta)K - w_1 L_1 - RK \quad (4)$$

and

$$\begin{aligned} \Pi_2 = & \{x(1+\bar{r})\psi K - d^s(1+\bar{r})\psi K\} \\ & + \{Az_2(1-\psi)^\alpha K^\alpha L_2^{1-\alpha} + (1-\delta)(1-\psi)K - w_2 L_2 - d(1-\psi)K\}. \end{aligned} \quad (5)$$

Expression (4) is the firm's profit in the good state of nature in which no liquidation takes place. Expression (5), the firm's profit in the crisis state, distinguishes revenues from the liquidation of capital and the sale of goods. The proceeds from the fire sale of a fraction  $\psi$  of the firm's capital stock,  $x\psi K$ , are used to retire debt in the interim period when creditors obtain the default return  $d^s$ . This activity is reflected in the first bracketed term in (5), where revenues from liquidation and loan payoffs are translated to international values at the production period, so that  $d^s$  is multiplied by  $1+\bar{r}$ . The second bracketed term in (5) is profit from the production and sale of goods, which uses labor and the remaining capital.

In equilibrium, the firm cannot make arbitrarily large profits (or losses) from liquidation. Hence, the first bracketed term in (5) must be zero, implying that  $d^s = x$ . Moreover, while the firm takes  $d$  and  $d^s$  as given in its optimization problem, lenders must earn the same return in the default state by lending short and long. Hence, the following arbitrage condition links short and long rates:

$$d = d^s(1+\bar{r}). \quad (6)$$

We now turn to the firm's optimization problem, which is constrained in two respects. First, UIP must hold: international capital markets will not fund investment unless firms pay international investors the world interest rate on average. Hence, firms understand that they must compensate creditors for the low return  $d$  they pay in the bad state by raising the return  $R$  they offer in the good state, implying

$$(1-\theta)\frac{\partial R}{\partial K} + \theta\frac{\partial d}{\partial K} = 0. \quad (7)$$

Second, because of limited liability, firms in default must turn over to their creditors all revenue from production after paying their wage bill. Hence, the default return  $d$  per unit of capital remaining after liquidation satisfies

$$Az_2(1-\psi)^\alpha K^\alpha L_2^{1-\alpha} + (1-\delta)(1-\psi)K - w_2 L_2 - d(1-\psi)K = 0. \quad (8)$$

With these preliminaries, we can now state the firm's first-order necessary conditions (FOCs). We focus on equilibria in which firms liquidate some (but not all) capital. The FOCs are

$$w_1 = (1-\alpha)z_1 A (K/L_1)^\alpha \quad (9)$$

$$w_2 = (1-\alpha)z_2 A (1-\psi)^\alpha (K/L_2)^\alpha. \quad (10)$$

$$\begin{aligned} \frac{\partial E\{\Pi\}}{\partial K} &= (1-\theta) \left[ \alpha z_1 A K^{\alpha-1} L_1^{1-\alpha} + 1 - \delta - R - K \frac{\partial R}{\partial K} \right] \\ &+ \theta \left[ \alpha z_2 A (1-\psi)^\alpha K^{\alpha-1} L_2^{1-\alpha} + x(1+\bar{r})\psi + (1-\delta)(1-\psi) - d - K \frac{\partial d}{\partial K} \right] = 0 \end{aligned} \quad (11)$$

$$\frac{\partial \Pi_2}{\partial \psi} = -\alpha A z_2 (1-\psi)^{\alpha-1} K^\alpha L_2^{1-\alpha} - (1-\delta)K + dK + (x-d^s)(1+\bar{r})K = 0. \quad (12)$$

Expressions (9)-(10), the FOCs for  $L_1$  and  $L_2$ , are the usual conditions requiring equality of the real wage with the marginal product of labor (MPL). Expression (11), the FOC for  $K$ , takes into account the need for investors to obtain the world interest rate on average. Expression (12) the FOC for  $\psi$ , is a productive efficiency condition in the crisis state that requires goods production and capital liquidation to generate the same return at the margin.

Appendix I proves that the FOCs (9)-(12) imply the following:

$$d = \alpha z_2 A (1-\psi)^{\alpha-1} (K/L_2)^{\alpha-1} + 1 - \delta. \quad (13)$$

$$d = x(1+\bar{r}) = d^s \quad (14)$$

$$R = z_1 \alpha A (K/L_2)^{\alpha-1} + 1 - \delta. \quad (15)$$

The first equality in (13) says that the rate of return investors obtain in the default state equals the MPK in that state. To establish it we use the FOC for  $L_2$ , equation (10), to substitute out  $w_2$  from (8), the zero profit condition in the default state. The second equality in (13) requires firms to equate the gross MPK in production with the gross return from liquidating capital. To establish it, begin with the FOC for  $\psi$ , condition (12), use the link between  $d$  and  $d^s$  from (6), and rearrange terms. Expression (14) is an arbitrage condition: firms are indifferent between making early loan payoffs involving a default return  $d^s=x$  in the intermediate period and a default payoff  $d$  at maturity. To arrive at (14) use (13), the firm's FOC with respect to  $L_2$ , expression (10), and the expression of the default state  $d$  from (8). Finally, expression (15) says that the return obtained by investors in the non-crisis state, denoted  $R$ , equals the MPK in that state. To establish (15), start with the FOC for  $K$ , expression (11), use (8) and the arbitrage conditions (14) and (10).

The final step in calculating the equilibrium is to use the full employment assumption  $L_1 = L_2 = \bar{L}$ . Substituting (14) and (15) in the UIP condition (1) yields the reduced form for the firm's choice of capital-labor ratio  $k = K / \bar{L}$  before liquidation:

$$\bar{k} = \left\{ \frac{\alpha A(1-\theta)z_1}{\bar{R} - [\theta x(1+\bar{r}) + (1-\theta)(1-\delta)]} \right\}^{\frac{1}{1-\alpha}} > 0. \quad (16)$$

Equation (16) can be substituted in equation (13) to obtain the fraction of capital remaining after liquidation,  $1-\psi$ :

$$1-\bar{\psi} = \left\{ \frac{z_2}{z_1} \frac{\bar{R} - [\theta x(1+\bar{r}) + (1-\theta)(1-\delta)]}{x(1+\bar{r}) - [\theta x(1+\bar{r}) + (1-\theta)(1-\delta)]} \right\}^{\frac{1}{1-\alpha}}. \quad (17)$$

We need to impose certain restrictions on parameter values to ensure that demand for capital is positive, that liquidation takes place, and that the country has some capital left over for production in a crisis. For the RHS of (16) to be positive,  $\bar{R} > \theta x(1+\bar{r}) + (1-\theta)(1-\delta)$ , which is always true for  $\bar{R} > 1$ ,  $1 > \delta > 0$ , and  $x \leq 1$ . For the economy to have capital left over after liquidation, the RHS of (17) must be positive. This is equivalent to requiring that  $x(1+\bar{r}) - [\theta x(1+\bar{r}) + (1-\theta)(1-\delta)] > 0$ , or  $x(1+\bar{r}) > 1-\delta$ , which we impose from now on.

The following unsurprising comparative static results are easy to establish from (16) and (17). Demand for capital increases if the world interest rate declines, if the liquidation price of capital rises, or the crisis probability drops.

Next, we establish that liquidation occurs if negative shocks are "large" and "rare." We already know that firms will not liquidate all their capital,  $\psi < 1$ , if

$\bar{R} > \theta x(1+\bar{r}) + (1-\theta)(1-\delta)$ . For *some* liquidation to take place, the RHS of (17) must be less than one, or

$$Z \equiv \frac{z_2}{z_1} < \frac{x(1+\bar{r}) - [\theta x(1+\bar{r}) + (1-\theta)(1-\delta)]}{\bar{R} - [\theta x(1+\bar{r}) + (1-\theta)(1-\delta)]} \equiv H(\theta) . \quad (18)$$

Now the RHS of (18) is a continuous function of  $\theta$ , say  $H(\theta)$ ,  $0 \leq \theta \leq 1$ . Function  $H$  has the following properties:  $H(0) = [x(1+\bar{r}) - (1-\delta)] / [\bar{R} - (1-\delta)]$  is positive and less than one;  $H(\theta)$  is decreasing in  $\theta$ ; and  $H(1) = 0$ . It follows that inequality (11) can not be satisfied if  $Z$  exceeds  $H(0)$ . This shows that “small” adverse shocks to productivity (values of  $Z$  above  $H(0)$ ) will not produce any liquidation regardless of how frequent they are. To trigger liquidation, shocks must be large enough: only values of  $Z$  below  $H(0)$  are permitted. To establish that disasters must also be rare to trigger liquidation, assume that  $Z$  is less than  $H(0)$ . Then no capital will be liquidated if  $\theta$  violates (11). The threshold probability above which there is no liquidation is the unique solution of  $Z = H(\theta)$ ,  $\theta = H^{-1}(Z)$ . See Figure 1. Clearly, greater disasters (smaller values of  $Z$ ) raise the threshold probability consistent with liquidation.

### III. THE ECONOMIC IMPLICATIONS OF LIQUIDATION

We turn now to the effects of liquidation on the developing country’s capital intensity, wages and worker welfare. Wages in the two production states are given by:

$$\bar{w}_1 = (1-\alpha)z_1 A (\bar{k})^\alpha \quad (19)$$

$$\bar{w}_2 = (1-\alpha)z_2 A (1-\bar{\psi})^\alpha (\bar{k})^\alpha . \quad (20)$$

In a crisis, workers face a twin shock: wages decline because TFP is expected to drop and because firms liquidate capital, which reduces the capital-labor ratio.

Constrast this outcome with an equilibrium in which liquidation is suppressed,  $\bar{\psi} = 0$ , and the capital-labor ratio is constant across the two states of nature,  $k_1 = k_2 = k^*$ . Workers still have to contend with the adverse TFP shock, but they are spared the decline in capital intensity associated with liquidation.

In an equilibrium with no liquidation, firms still maximize profits under limited liability and UIP. The demand for capital is derived from equations (1), (13) and (15), yielding:

$$k^* = \left( \frac{\alpha A [(1-\theta)z_1 + \theta z_2]}{\bar{R} - (1-\delta)} \right)^{\frac{1}{1-\alpha}}. \quad (21)$$

It is useful to compare expression (21), which characterizes the developing country's demand for capital with the liquidation option suppressed, with the level prevailing when liquidation takes place, equation (16). It can be shown that if condition (18) is satisfied, so that  $\bar{\nu} > 0$ , then  $\bar{k}$  is *higher* than  $k^*$  and  $\bar{k}_2 = (1-\bar{\nu})\bar{k}$  is *lower* than  $k^*$ . When firms exercise the option of liquidating capital in a disaster, they demand more capital, borrow more, and produce more real output in the non-crisis state. But liquidation lowers capital intensity and output on the rare occasions when a crisis hits.

The increased volatility associated with capital liquidation lowers worker welfare. To see this, consider wages in the no-liquidation equilibrium:

$$w_1^* = (1-\alpha)z_1 A(k^*)^\alpha \quad (22)$$

$$w_2^* = (1-\alpha)z_2 A(k^*)^\alpha \quad (23)$$

Because  $\bar{k}$  is *higher* than  $k^*$  but  $\bar{k}_2$  is *lower* than  $k^*$ , it follows that  $\bar{w}_1 > w_1^*$  and  $\bar{w}_2 > w_2^*$ . Wages when liquidation is not exercised are *lower* in normal times and *higher* in hard times. It turns out that workers' Expected Utility (EU) is higher when liquidation is not possible ( $EU_{NLP} > EU_{LP}$ ) for preferences with CRRA coefficients greater than or equal to one (See Appendix II). Workers would be better off in the no-liquidation equilibrium in which the mean wage and the variance of wages are lower relative to the liquidation equilibrium.

What about the effects of capital liquidation on foreign investors? Because these investors are well diversified and risk-neutral, they are unaffected by capital liquidation. In the no liquidation equilibrium, the returns to investors in the two states are

$$R^* = z_1 \alpha A(k^*)^{\alpha-1} + 1 - \delta \quad (24)$$

$$d^* = z_2 \alpha A(k^*)^{\alpha-1} + 1 - \delta. \quad (25)$$

Because  $\bar{k} > k^*$ , the no-liquidation equilibrium features a lower rate of return in the good state and a higher return in the bad state:  $\bar{R} < R^*$  and  $\bar{d} > d^*$ . But UIP requires that investors are compensated by higher returns in the bad state, so that they earn the world interest rate in expected value terms.

#### IV. INTERNATIONAL RESERVES

In the absence of private wage insurance, public policy can strive to improve worker welfare by reducing (or eliminating) fire sales of capital and lowering the variability of wage incomes. A direct approach of providing government wage insurance would be a first-best solution to the problem and one that should be followed in the long run. Many emerging countries have indeed responded to crises in the 1990s by strengthening their social insurance and safety net mechanisms. With the support of the international community, they made room in their budgets for additional spending for affected workers and took steps to expand their permanent social insurance mechanisms. As mentioned in the Introduction, these institutional improvements take time and may face obstacles. So in the short run, countries have found it very useful to build up their fiscal and financial cushions.

In this Section, we analyze a second-best response to dealing with capital liquidation that could be followed in the short run. We consider a reserve requirement scheme similar to the one Chile imposed on short-term, hot money: for every dollar of foreign capital banks on-lend to domestic firms, a fraction  $g$  must be deposited with the recipient country's central bank. The central bank earns the world rate of interest on the proceeds. If the TFP signal is negative, it extends emergency loans to firms on condition that they reduce capital liquidation dollar for dollar. The scheme works because one distortion (taxation of inflows) offsets the undesirable effects of a second (income volatility caused by lack of wage insurance for workers).

The stock of reserves thus raised amounts to  $L^{cb} = (1 + \bar{r})gK$  dollars. If the good TFP state is signaled, this stock is reinvested and is distributed to domestic banks at the end of the production period. If the bad signal is observed, the central bank makes the reserves available to firms at rate  $r^{cb}$  in the intermediate period, where  $-1 \leq r^{cb} \leq \bar{r}$ . The loans are priced so that firms willingly reduce liquidation dollar for dollar. The quantity of loans paid off early,  $L$ , comes from resources raised from liquidation,  $x\psi K$ , and central bank credit,  $L^{cb}$ , adjusted for the "haircut" on principal:

$$L = \frac{x\psi K + L^{cb}}{d^s}. \quad (26)$$

As already discussed in the analysis of the firm's profit maximization problem, in equilibrium,  $d^s$  must be such that banks are indifferent between calling in loans early and waiting to obtain the default return,  $d$ , implying that

$$d = d^s(1 + \bar{r}). \quad (27)$$

Because central bank loans are tied, their quantity must equal the reduction in liquidation, or  $L^{cb} = x(\bar{\psi} - \psi)K$ , and funds available for early loan repayments are  $F = x\psi K + L^{cb} = x\bar{\psi}K$ .

To have sufficient resources to meet its target for liquidation reduction, the central bank sets  $g$  so that  $(1+\bar{r})gK = x(\bar{\psi} - \psi)K$ , implying

$$\psi = \bar{\psi} - \frac{(1+\bar{r})g}{x}. \quad (28)$$

Equation (28) provides the link between the target  $\psi$  and the reserve requirement  $g$ . More ambitious targets for suppressing liquidation (lower value of  $\psi$ ) necessitate more international reserves accumulation and higher reserve requirements on inflows.

We now turn to the question of the pricing of emergency loans. A firm's choice of these loans depends on their gross cost,  $1+r^{cb}$ , and on the benefits of reducing liquidation. In a crisis, a dollar of central bank funding buys  $1/x$  units of capital. Withdrawing a unit of capital from liquidation yields a benefit  $R_2$  equal to the MPK in the bad state. Hence, the benefit of a dollar of tied central bank credit is  $R_2/x$ . Firms that treat  $r^{cb}$  as given will maximize profits by liquidating an amount of capital that equalizes the cost and benefit of central bank lending:

$$1+r^{cb} = \frac{R_2}{x}. \quad (29)$$

Equation (29) is the demand function for emergency loans. The central bank is aware that (29) must be met in setting its policy instruments  $r^{cb}$  and  $g$ .

To compute the developing country's demand for capital under the reserve requirement scheme, we start with the rates of return obtained by domestic banks in the two states, which we denote  $(R_1, R_2)$ . Because these banks are costless and competitive,  $(R_1, R_2)$  are also the returns of their foreign lenders. Consider the return on a dollar loaned by a foreign lender to an emerging market bank that is subject to a reserve requirement  $g$ . A fraction  $\lambda = g/(1+g)$  of this dollar must be deposited with the emerging market central bank, while the rest can be funneled to investment projects. Bank returns are therefore a weighted average of the returns on physical capital and the returns on international reserves in each state, or

$$R_1 = (1-\lambda)R + \lambda\bar{R} \quad (30)$$

and

$$R_2 = (1-\lambda)d + \lambda\bar{R}^{cb}, \quad (31)$$

where  $\bar{R}^{cb} = (1+\bar{r})(1+r^{cb})$  is the two-period return on reserves in the bad state. As usual, the  $(R_1, R_2)$  pair must also satisfy UIP:

$$(1-\theta)R_1 + \theta R_2 = \bar{R}. \quad (32)$$

In addition, in equilibrium we have  $L_1 = L_2 = \bar{L}$ ,  $k_1 = K/\bar{L} \equiv k$ , and  $k_2 \equiv (1-\psi)k$ , where the liquidation fraction  $\psi$  is set by policy (see equation (28)). Profit maximization requires equality of wages to MPLs and of investment returns to gross MPKs:

$$R_1 = z_1 \alpha A k^{\alpha-1} + 1 - \delta. \quad (33)$$

$$R_2 = z_2 \alpha A k_2^{\alpha-1} + 1 - \delta. \quad (34)$$

Substituting (33)-(34) in (32) and noting that  $\psi$  is a function of  $g$  from equation (28) yields the expression for  $k$ :

$$\bar{R} = (1-\theta) \left[ 1 - \delta + \alpha A z_1 k^{\alpha-1} \right] + \theta (1-\psi) \left[ 1 - \delta + \alpha A z_2 (1-\psi)^{\alpha-1} k^{\alpha-1} \right] + \theta \psi x (1 + \bar{r}). \quad (35)$$

The RHS of (36) is the expected value of the MPK across the two states. In the good state, we take the MPK of the entire  $k$ . In the bad state, it is appropriate to consider the weighted average of the MPK of unliquidated capital and the return, evaluated at world rates,  $x(1+\bar{r})$ , of liquidated amounts. Simplifying and rearranging, we obtain  $k$ :

$$k = \left[ \frac{\alpha A \left[ (1-\theta) z_1 + \theta z_2 (1-\psi)^\alpha \right]}{\bar{R} - (1-\delta) - \theta \psi \left( x(1+\bar{r}) - (1-\delta) \right)} \right]^{\frac{1}{1-\alpha}}. \quad (36)$$

How does the demand for capital in (36) depend on the reserve requirement? The RHS of (36) depends on  $g$  indirectly, through the authorities' target for liquidation  $\psi$  (see equation (28)). It can be verified that in the absence of policy,  $g=0$ ,  $\psi = \bar{\psi}$  and  $k = \bar{k}$ , and that as  $g$  rises,  $\psi$  and  $k(g)$  in (36) both decline. If the authorities choose a high enough value of  $g$ , they will suppress all liquidation:  $g^{\max} = x\bar{\psi}/(1+\bar{r})$  implies  $\psi = 0$  and  $k = k^*$ . See Figure 2.

In sum, higher reserve requirements have the intended effect: they allow the central bank to amass greater financial resources, which are then employed in a crisis to reduce liquidation. Because  $\psi$  declines as  $g$  rises, the scheme raises demand for capital in the bad TFP state:

$k_2 = k_2(g)$  as given implicitly by

$$k_2(g) = (1-\psi(g))k(g), \quad (37)$$

increases as the reserve requirement  $g$  rises.



We turn next to the pricing of emergency loans. To ensure that firms willingly absorb emergency funds, central bank policy must ensure that equation (29) is satisfied. Using (28), (36) and (37), in equation (29) pins down the interest rate on central bank loans:

$$r^{cb}(g) = \frac{z_2 \alpha A (k_2(g))^{\alpha-1} + (1-\delta)}{x} - 1. \quad (38)$$

Expression (38) makes clear that the implicit subsidy of central bank loans,  $\bar{r} - r^{cb}(g)$ , rises as the reserve requirement increases. In other words, ambitious targets for suppressing liquidation require the provision of greater financial incentives to firms. This is because  $k_2(g)$  is increasing in  $g$ , so that the MPK in a crisis declines as  $g$  rises. From equation (38), this translates into a lower interest rate on central bank emergency credit. See Figure 3.

An important question concerns the value of  $g$  that maximizes workers' expected utility. It turns out that for conventional values of capital intensity ( $\alpha$  around 0.33), a policy that eliminates all capital liquidation is optimal from the point of view of workers. The reason is that the decline in average wages resulting from taxation of inflows is small while the benefit from lower wage variability is large. The optimal value of  $g$  is  $g^{\max} = x\bar{r} / (1 + \bar{r})$ , which suppresses all liquidation and produces the no-liquidation capital-labor ratio  $k(g^{\max}) = k^*$ . The haircut price declines following the introduction of the scheme:  $h < x$ : the scheme adds to the supply of funds available to repay loans early, and the price of these loans declines.

## V. CALIBRATION

We calibrate the model to illustrative but plausible parameter values. The objective is to provide a rough quantitative sense of the welfare effects of international reserves policy.

$$\{\theta, z_1, z_2, \alpha, A, x, \delta, \bar{r}\} = \{0.10, 0.33, 1.0, 0.33, 1.0, 0.90, 0.19, 0.05\}.$$

The country is assumed to face a rare disaster: there is a 10 percent chance of a TFP shock that cuts TFP to one third of its value in normal times. As discussed in the Introduction, these shocks could be related to technological change, terms of trade disturbances, and even political and institutional upheaval. The capital intensity of production is one third, as conventionally assumed. The annual rate of depreciation of capital is 10 percent, yielding a two-year depreciation rate of 19 percent. The liquidation price of capital is 0.90, equal the one period rate of depreciation. The world interest rate is 5 percent. We examine a range of preferences for worker utility. Our baseline is a coefficient of relative risk aversion (CRRA) of  $\gamma=2$ , which represents a moderate degree of risk aversion. We also examine logarithmic

preferences,  $\gamma=1$ , which is a very mild form of risk aversion, and  $\gamma=4$ , which is stronger but still reasonable aversion to risk.

As already indicated, policy makers set the reserve requirement on capital inflows in order to maximize domestic workers' expected utility. In the welfare comparisons, we follow the standard approach in the Real Business Cycle (RBC) literature. Workers would need to receive compensation in order to make up utility losses due to additional liquidation-related volatility of wages. This compensation, denoted  $c$ , is the percentage increase in wages that workers must receive in the absence of reserves policy to make them as well off as they are under the policy.  $c$  solves the equation  $E\{U(w_1, w_2)\} = E\{U((1+c)w_{1LF}, (1+c)w_{2LF})\}$ , where  $(w_1, w_2)$  are wages under the reserves policy and  $(w_{1LF}, w_{2LF})$  are wages in its absence.

It turns out that this welfare measure of wage variability is very sensitive to the degree of worker risk aversion. The baseline results ( $\gamma=2$ ) indicate that large stocks of international reserves are needed to protect workers in emerging markets against large, infrequent shocks (Table 2). Column 1 shows the policymakers' choice of reserves in relation to foreign debt ( $g$ , in percent) up to the ceiling  $g = g^{\max}$  that suppresses all capital liquidation. Column 2 shows the reserve ratio imposed on domestic banks ( $\lambda$ , in percent); Column 3 is the fraction of capital liquidated in a crisis ( $\psi$ ) as a function of  $g$ . Column 4 is the ratio of international reserves to good-state GDP. Column 5 is the percentage change in expected utility (compensation measure) relative to no-policy. Column 6 is the percentage change in expected wage relative to no-policy. Column 7 shows that percentage change in the coefficient of variation of wages,  $SD_w/E_w$ , relative to no-policy. Column 8 shows the utility compensation measure for log preferences ( $\gamma = 1$ ), and column 9 does the same for  $\gamma = 4$ .

Table 2 underscores several points.

- The reserves policy raises welfare by achieving a substantial reduction in wage variability, with little change in the level of expected wages.
- The optimal reserves policy is to reduce *all* wage variability and suppress all capital liquidation in a crisis.
- In our calibration, the reserve requirement on capital inflows that maximizes workers' expected utility is  $g=28$  percent of all foreign-financed capital investment. This scheme can be implemented by imposing a requirement that domestic banks deposit at the central bank  $\lambda=22$  percent of their foreign borrowing.
- At 30 percent of GDP, the war chest of international reserves under the optimal policy is large by conventional standards, though not far from the stocks accumulated in some developing countries in recent years.

- The effect of reserves on welfare depends on workers' attitude toward risk. With a CRRA  $\gamma=2$ , compensation of 3 percent of wages is needed to offset wage variability associated with capital liquidation. The welfare cost of crises drops to about one percent of wages if utility is logarithmic,  $\gamma=1$ , but rises to 10 percent of wages if  $\gamma=4$ .

The example is suggestive: neoclassical models of investment with a capital liquidation option can generate large precautionary holdings of reserves. In a second-best context in which direct wage insurance is not available to workers, large reserves are useful to limit the liquidation of capital and safeguard the welfare of workers in a crisis. Optimal reserves are large in the model because capital liquidation in a crisis is extensive (over 33 percent of the entire capital stock).

It is worthwhile to conduct some sensitivity analysis to ascertain how optimal reserves depend on the demand for capital and the desired amount of liquidation. One important parameter is the assumption about "time to build." In our example, a model period corresponded to a calendar year. Yet, many projects in developing countries may take longer to complete. Consider a second example in which time to build doubles from two to four years, which makes a model period equivalent to two calendar years. Cumulative depreciation is then  $\delta = 0.3439 = .1 + .9 + .81 + .0729$ , the net international interest rate is  $\bar{r} = 0.1025 (= 1.05^2 - 1)$ , and the gross two-period world interest rate is  $\bar{R} = 1.2155$ . To be consistent with the example, we set  $x$  at 0.81, which corresponds to a depreciation of 0.19 over a model period. We also consider a third example in which  $x$  is raised to 0.90.

Extending time-to-build requirements while holding the world interest rate constant makes investment projects less attractive and reduces the developing country's demand for capital:  $\bar{k} = 0.419$ , compared to about one in the original example. The results for  $x=0.81$  indicate a lower liquidation fraction,  $\bar{\psi} = 0.23$ . The optimal reserves ratio is  $g^{\max} = 0.17$ , and optimal reserves are the equivalent of 9 ½ percent of GDP. Somewhat surprisingly, the utility gain of this smaller reserves stock is still large, amounting to about 2 percent of wage income. Because the capital intensity of this economy is lower than in our original example, the sensitivity of wage income to the TFP shock is larger.

If the liquidation value of capital is raised to  $x = 0.9$ , liquidation becomes much more attractive, and desired liquidation shoots up to  $\bar{\psi} = 0.56$ , optimal reserves rise to the equivalent of 25 percent of GDP, and the welfare benefit of reserves is over 6 percent of no-policy wages. The higher liquidation price also raises demand for capital:  $\bar{k} = 0.43$ . Taken together, the three examples illustrate that the demand for capital, the liquidation fraction, and the optimal reserves cover are very sensitive to the length of time to build, to the liquidation price and to the depreciation rate of capital.

## VI. THE REAL EXCHANGE RATE

Up to this point, our discussion has abstracted from movements in the real exchange rate (RER), which are, along with maturity mismatches and the arrival of unfavorable information about the emerging market, a noteworthy feature of financial crises.

This Section extends the analysis by considering an emerging country in which foreign investment is channeled to either the traded or the nontraded goods sector. We continue to assume that investment is financed from foreign sources, subject to UIP and the liquidation option. The main results obtained earlier carry through in the two-sector environment, and new insights are gained concerning movements in the equilibrium RER in a crisis. The crisis itself is precipitated by signals indicating a shift in the TFP in the traded goods sector, a device meant to approximate movements in the country's terms of trade.<sup>4</sup> Once the bad signal is observed, capital liquidation beings on an economy-wide basis.

The main conclusions of the analysis of the two-sector model are as follows:

- The fraction of capital liquidated is the same as in the one sector model, and the extent of liquidation is the same in the two sectors:  $\psi_N = \psi_T = \bar{\psi}$ .
- Assuming that nontraded goods are more labor intensive than traded goods, the extent of RER depreciation in a crisis depends on the depth of liquidation and on the difference in the capital intensities in production in the two sectors.
- The optimal policy is still to suppress all liquidation. The optimal reserves policy results in lower RER variability. This benefits workers, who gain from the reserves policy by having less variable real wages and by facing a less variable RER.

To establish these results, consider a representative firm that produces both traded and nontraded goods and selects  $\{L_{1T}, L_{1N}, L_{2T}, L_{2N}, K_T, K_N, \psi_T, \psi_N\}$  to maximize expected profit

$$E\{\Pi\} = (1 - \theta)\Pi_1 + \theta\Pi_2,$$

where

$$\begin{aligned} \Pi_1 = & \left\{ A_T z_1 K_T^\alpha L_{1T}^{1-\alpha} + (1 - \delta) K_T - w_1 L_{1T} - R K_T \right\} \\ & + \left\{ p_{N1} A_N K_N^\beta L_{1N}^{1-\beta} + (1 - \delta) K_N - w_1 L_{1N} - R K_N \right\} \end{aligned} \quad (39)$$

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<sup>4</sup> Formally, in this two good model terms of trade shocks are different from TFP shocks. The difference is the following:

and

$$\begin{aligned} \Pi_2 = & \left\{ x(1+\bar{r})(\psi_T K_T + \psi_N K_N) - d^s(1+\bar{r})(\psi_T K_T + \psi_N K_N) \right\} \\ & + \left\{ A_T z_2 (1-\psi_T)^\alpha K_T^\alpha L_{2T}^{1-\alpha} + (1-\delta)(1-\psi_T)K_T - w_2 L_{2T} - d(1-\psi_T)K_T \right\} \\ & + \left\{ p_{N2} A_N (1-\psi_N)^\beta K_N^\beta L_{2N}^{1-\beta} + (1-\delta)(1-\psi_N)K_N - w_2 L_{2N} - d(1-\psi_N)K_N \right\}. \end{aligned} \quad (40)$$

Expression (39) is the firm's profit in the good state of nature in which no liquidation takes place. Expression (40), the firm's profit in the crisis state, distinguishes revenues from the liquidation of capital and from the sale of goods. In the interim period, following the bad signal, the firm uses the proceeds its fire sale of capital,  $x(\psi_T K_T + \psi_N K_N)$ , to retire debt early, with creditors obtaining a default return  $d^s$ . The revenue from the fire sale and the loan payoff are reflected in the first bracketed term in (40), where both are translated to international values at the production period by multiplying them by  $1+\bar{r}$ . The second and third bracketed terms in (40) are profits from the production and sale of traded and nontraded goods, which use labor and the remaining capital. Notice that the relative price of nontraded goods depends on the state of nature.

In equilibrium, the firm cannot make arbitrarily large profits (or losses) from liquidation. Hence, the first bracketed term in (40) must be zero, implying that  $d^s = x$ . Moreover, while the firm takes  $d$  and  $d^s$  as given in its optimization problem, lenders must earn the same return in the default state by lending short and long. Hence, the following arbitrage condition links short and long rates:

$$d = d^s(1+\bar{r}). \quad (41)$$

The firm's optimization problem is constrained by UIP, implying, as before, that the state-contingent rates of return obtained by firm creditors satisfy

$$(1-\theta)\frac{\partial R}{\partial K} + \theta\frac{\partial d}{\partial K} = 0. \quad (42)$$

In addition, limited liability implies that defaulting firms in the bad state of nature turn over to their creditors all revenue from production after paying their wage bill. Hence, the default return  $d$  per unit of capital remaining after liquidation is given by

$$\begin{aligned} 0 = & \left\{ A_T z_2 (1-\psi_T)^\alpha K_T^\alpha L_{2T}^{1-\alpha} + (1-\delta)(1-\psi_T)K_T - w_2 L_{2T} - d(1-\psi_T)K_T \right\} \\ & + \left\{ p_{N2} A_N (1-\psi_N)^\beta K_N^\beta L_{2N}^{1-\beta} + (1-\delta)(1-\psi_N)K_N - w_2 L_{2N} - d(1-\psi_N)K_N \right\}. \end{aligned} \quad (43)$$

In an equilibrium in which both traded and nontraded goods are produced and some capital is liquidated, the firm's FOCs are:

$$w_1 = (1-\alpha)z_1 A_T (K_T / L_{1T})^\alpha = p_{N1}(1-\beta)A_N (K_N / L_{1N})^\beta \quad (44)$$

$$w_2 = (1-\alpha)z_2 A_T (1-\psi_T)^\alpha (K_T / L_{2T})^\alpha = p_{N2}(1-\beta)A_N (1-\psi_N)^\beta (K_N / L_{2N})^\beta. \quad (45)$$

$$\begin{aligned} \frac{\partial E\{\Pi\}}{\partial K_T} = 0 &= (1-\theta) \left[ \alpha z_1 A_T K_T^{\alpha-1} L_{1T}^{1-\alpha} + 1 - \delta - R - K_T \frac{\partial R}{\partial K_T} \right] \\ &+ \theta \left[ x(1+\bar{r}) - d^s(1+\bar{r}) \right] \psi_T \\ &+ \theta \left[ \alpha z_2 A_T (1-\psi_T)^\alpha K_T^{\alpha-1} L_{2T}^{1-\alpha} + (1-\delta)(1-\psi_T) - d(1-\psi_T) - (1-\psi_T)K_T \frac{\partial d}{\partial K_T} \right] \end{aligned} \quad (46)$$

$$\begin{aligned} \frac{\partial E\{\Pi\}}{\partial K_N} = 0 &= (1-\theta) \left[ \beta p_{N1} A_N K_N^{\beta-1} L_{1N}^{1-\beta} + (1-\delta) - R - K_N \frac{\partial R}{\partial K_N} \right] \\ &+ \theta \left[ x(1+\bar{r}) - d^s(1+\bar{r}) \right] \psi_N \\ &+ \theta \left[ \beta p_{N2} A_N (1-\psi_N)^\beta K_N^{\beta-1} L_{2N}^{1-\beta} + (1-\delta)(1-\psi_N) - d(1-\psi_N) - (1-\psi_N)K_N \frac{\partial d}{\partial K_N} \right] \end{aligned} \quad (47)$$

$$\frac{\partial \Pi_2}{\partial \psi_T} = 0 = K_T (x - d^s)(1+\bar{r}) - K_T \left[ \alpha A_T z_2 (1-\psi_T)^{\alpha-1} K_T^{\alpha-1} L_{2T}^{1-\alpha} + 1 - \delta - d \right]. \quad (48)$$

$$\frac{\partial \Pi_2}{\partial \psi_N} = 0 = K_N (x - d^s)(1+\bar{r}) - K_N \left[ \beta p_{N2} A_N (1-\psi_N)^{\beta-1} K_N^{\beta-1} L_{2N}^{1-\beta} + 1 - \delta - d \right]. \quad (49)$$

Expressions (44)-(45), the FOCs for  $L_1$  and  $L_2$ , are the usual conditions requiring equality of the real wage with the marginal product of labor (MPL). Expressions (46)-(47), the FOC for  $K_T$  and  $K_N$ , take into account the need for investors to obtain the world interest rate on average. Expressions (48)-(49) the two FOCs for  $\psi_T$  and  $\psi_N$  are productive efficiency conditions requiring production of goods and capital liquidation to generate the same return at the margin. They imply the usual conditions that the rate of return to investors in the bad state,  $d$ , equals the MPK in the two traded and nontraded sectors.

$$d = \alpha A_T z_2 (1-\psi_T)^{\alpha-1} K_T^{\alpha-1} L_{2T}^{1-\alpha} + 1 - \delta = \beta p_{N2} A_N (1-\psi_N)^{\beta-1} K_N^{\beta-1} L_{2N}^{1-\beta} + 1 - \delta \quad (50)$$

Moreover, we have

$$d = x(1+\bar{r}) \quad (51)$$

Also, the MPK in the good state must equal the return to investors in that state:

$$R = z_1 \alpha A_T (K_T / L_{1T})^{\alpha-1} + 1 - \delta = p_{N1} \beta A_N (K_N / L_{1N})^{\beta-1} + 1 - \delta \quad (52)$$

Equilibrium also requires that all available labor is fully employed,

$$L_{1T} + L_{1N} = \bar{L} \quad \text{and} \quad L_{2T} + L_{2N} = \bar{L}, \quad (53)$$

and that demand for non-traded goods equals supply in each state of nature:

$$C_{N1} = Y_{N1} = A_N K_N^\beta L_N^{1-\beta} \quad \text{and} \quad C_{N2} = Y_{N2} = A_N (1 - \psi_N)^\beta K_N^\beta L_N^{1-\beta}. \quad (54)$$

We now derive demand functions for traded and nontraded goods assuming that preferences are logarithmic:

$$E\{u(c)\} = (1 - \theta) [\log(c_{1T}) + \zeta \log(c_{1N})] + \theta [\log(c_{2T}) + \zeta \log(c_{2N})]. \quad (55)$$

Workers maximize  $E\{u(c)\}$  subject to the budget constraint

$$c_{1T} + p_{1N} c_{1N} = w_1 \quad \text{and} \quad c_{2T} + p_{2N} c_{2N} = w_2, \quad (56)$$

leading to the demand functions in (57):

$$c_{1T} = \frac{1}{1 + \zeta} w_1 \quad p_{1N} c_{1N} = \frac{\zeta}{1 + \zeta} w_1 \quad (57a)$$

$$c_{2T} = \frac{1}{1 + \zeta} w_2 \quad p_{2N} c_{2N} = \frac{\zeta}{1 + \zeta} w_2. \quad (57b)$$

In equilibrium, in the nontraded sector in the non-crisis state, we must have  $C_{1N} = Y_{1N}$ , where  $C_{1N} \equiv \bar{L} c_{1N}$  is aggregate consumption, implying that

$$C_{1N} = \bar{L} \frac{\zeta}{1 + \zeta} \frac{w_1}{p_{1N}} = \bar{L} \frac{\zeta}{1 + \zeta} [(1 - \beta) A_N (K_N / L_{1N})^\beta] = Y_{1N}, \quad (58)$$

where the second equality in (58) uses the equality of the real wage to the MPL in the nontraded sector. Equation (58) can be written

$$\bar{L} \frac{\zeta}{1+\zeta} \left[ (1-\beta) A_N (K_N / L_{1N})^\beta \right] = A_N K_N^\beta L_{1N}^{1-\beta}, \quad (59)$$

which can be solved for  $L_{1N}$ , yielding the equilibrium supply of labor in the non-traded and traded sectors

$$L_{1N} = \frac{\zeta(1-\beta)}{1+\zeta} \bar{L}. \quad (60a)$$

$$L_{1T} \equiv \bar{L} - L_{1N} = \frac{1+\zeta\beta}{1+\zeta} \bar{L}. \quad (60b)$$

Similar calculations for equilibrium in the nontraded sector in the crisis state yield the same labor allocations:

$$L_{2N} = \frac{\zeta(1-\beta)}{1+\zeta} \bar{L}. \quad (61a)$$

$$L_{2T} \equiv \bar{L} - L_{2N} = \frac{1+\zeta\beta}{1+\zeta} \bar{L}. \quad (61b)$$

Having calculated  $L_{1T}$ , we use UIP, equation (1), to calculate the capital-labor ratio in the traded sector. We substitute  $d = x(1+\bar{r})$ , and  $R = z_1 \alpha A_T (K_T / L_{1T})^{\alpha-1} + 1 - \delta$  into the UIP and solve for  $k_T$ . The structure of this problem is the same as in the one-sector model, with  $K$  in the one sector model replaced here by  $K_T$ , and  $L$  replaced here by  $L_{1T}$ . We conclude that in an equilibrium with liquidation of the two-sector model, the capital-labor ratio in the traded sector is the same as the aggregate capital-labor ratio in the one good economy:

$$\bar{k}_{1T} \equiv \frac{\bar{K}_T}{\bar{L}_{1T}} = \left\{ \frac{\alpha A(1-\theta) z_1}{\bar{R} - [\theta x(1+\bar{r}) + (1-\theta)(1-\delta)]} \right\}^{\frac{1}{1-\alpha}}. \quad (62)$$

Next, we calculate the capital-labor ratio in the non-traded sector and the relative price of the non-traded good using the equality of wage rates and returns to capital in the two sectors:

$$w_1 = (1-\alpha) z_1 A_T (K_T / L_{1T})^\alpha = p_{N1} (1-\beta) A_N (K_N / L_{1N})^\beta \quad (63)$$

$$R = z_1 \alpha A_T (K_T / L_{1T})^{\alpha-1} + 1 - \delta = p_{N1} \beta A_N (K_N / L_{1N})^{\beta-1} + 1 - \delta \quad (64)$$



Eliminating all prices from (63)-(64) yield the well-known relationship between the sectoral capital intensities:

$$\frac{K_N}{L_{1N}} = \frac{\beta(1-\alpha)}{\alpha(1-\beta)} \frac{K_T}{L_{1T}}, \quad (65)$$

which implies

$$k_{1N} \equiv \frac{K_N}{L_{1N}} = \frac{\beta(1-\alpha)}{\alpha(1-\beta)} \left\{ \frac{\alpha A(1-\theta)z_1}{\bar{R} - [\theta x(1+\bar{r}) + (1-\theta)(1-\delta)]} \right\}^{\frac{1}{1-\alpha}} \quad (66)$$

The equilibrium price of nontraded good in the non-crisis state is therefore

$$p_{1N} = \left( \frac{\alpha}{\beta} \right)^\beta \left( \frac{1-\alpha}{1-\beta} \right)^{1-\beta} \frac{z_1 A_T}{A_N} \left\{ \frac{\alpha A(1-\theta)z_1}{\bar{R} - [\theta x(1+\bar{r}) + (1-\theta)(1-\delta)]} \right\}^{\frac{\alpha-\beta}{1-\alpha}} \quad (67)$$

Finally, the aggregate demand for capital in the economy is

$$K \equiv K_T + K_N = k_{1T} L_{1T} + k_{1N} L_{1N} = \frac{\alpha + \zeta\beta}{\alpha + \alpha\zeta} k_{1T} \bar{L}. \quad (68)$$

It follows that the economy-wide capital-labor ratio in the equilibrium with liquidation is

$$\bar{k} \equiv \frac{\bar{K}}{\bar{L}} = \frac{\alpha + \zeta\beta}{\alpha + \alpha\zeta} \left\{ \frac{\alpha A(1-\theta)z_1}{\bar{R} - [\theta x(1+\bar{r}) + (1-\theta)(1-\delta)]} \right\}^{\frac{1}{1-\alpha}}. \quad (69)$$

We note that if the nontraded sector is more (less) labor intensive than the traded sector, or  $\beta < \alpha$  ( $\beta > \alpha$ ), then the economy demands less (more) capital than the one-sector model.

We now turn to the determination of the capital liquidation fraction in each sector. Starting from the traded goods sector, we use the condition that

$$d = \alpha A_T z_2 (1 - \psi_T)^{\alpha-1} K_T^{\alpha-1} L_{2T}^{1-\alpha} + 1 - \delta = x(1 + \bar{r}) \quad (70)$$

Since the ratio  $K_T/L_T$  equals  $\bar{k}$ , we can solve the above for  $1 - \psi_T$ . But this is exactly the same problem we solved for in the one sector model; hence,  $\bar{\psi}_T = \bar{\psi}$ .

Next, we use the conditions

$$d = x(1+\bar{r}) = \beta p_{2N} A_N (1-\psi_N)^{\beta-1} K_N^{\beta-1} L_{2N}^{1-\beta} + 1 - \delta \quad (71)$$

and

$$(1-\alpha)z_2 A_T (1-\psi_T)^\alpha (K_T / L_{2T})^\alpha = p_{2N} (1-\beta) A_N (1-\psi_N)^\beta (K_N / L_{2N})^\beta (= w_2) \quad (72)$$

to solve for  $p_{2N}$  and  $\psi_N$ . After some algebra, this yields  $\bar{\psi}_N = \bar{\psi}$  (see Appendix III). In other words, the firm liquidates the same fraction of its capital stock in the two sectors.

The last step is to calculate the equilibrium price of nontraded goods in the crisis state. For this, we use (72) and the equilibrium value of  $K_T / L_T = \bar{k}$ :

$$p_{2N} = \alpha^\beta (1-\alpha)^{1-\beta} \beta^{-\beta} (1-\beta)^{\beta-1} \frac{z_2 A_T}{A_N} \frac{(1-\psi_T)^\alpha}{(1-\psi_N)^\beta} (K_T / L_T)^{\alpha-\beta} \quad (73)$$

$$\Rightarrow p_{2N} = \left(\frac{\alpha}{\beta}\right)^\beta \left(\frac{1-\alpha}{1-\beta}\right)^{1-\beta} \frac{z_2 A_T}{A_N} [(1-\bar{\psi})(K_T / L_T)]^{\alpha-\beta}. \quad (74)$$

Recall the expression for  $p_{1N}$ ,

$$, \quad (75)$$

and the definition of  $\bar{k} = K_T / L_T$ , to arrive at

$$p_{1N} = \left(\frac{\alpha}{\beta}\right)^\beta \left(\frac{1-\alpha}{1-\beta}\right)^{1-\beta} \frac{z_1 A_T}{A_N} \{K_T / L_T\}^{\alpha-\beta}. \quad (76)$$

It follows that

$$\frac{p_{1N}}{p_{2N}} = \frac{\left(\frac{\alpha}{\beta}\right)^\beta \left(\frac{1-\alpha}{1-\beta}\right)^{1-\beta} \frac{z_1 A_T}{A_N} \{K_T / L_T\}^{\alpha-\beta}}{\left(\frac{\alpha}{\beta}\right)^\beta \left(\frac{1-\alpha}{1-\beta}\right)^{1-\beta} \frac{z_2 A_T}{A_N} [(1-\bar{\psi})(K_T / L_T)]^{\alpha-\beta}},$$

which implies that the gross RER depreciation is given by

$$\frac{p_{2N}}{p_{1N}} = \frac{z_2}{z_1} (1-\bar{\psi})^{\alpha-\beta}. \quad (77)$$

Assuming that the non-traded sector is more labor intensive than the traded sector, or  $\alpha > \beta$ , in an equilibrium with liquidation, the term  $(1 - \bar{\nu})^{\alpha - \beta}$  is less than one. In addition, the term  $z_2/z_1$  is also less than one. It follows that the RER depreciates more in the equilibrium with liquidation than in the equilibrium in which liquidation is not possible (or is suppressed by policy). The additional, liquidation-induced RER depreciation depends on the share of capital liquidated in a crisis and on the difference in capital intensities in the two sectors.

Assuming that elimination of all liquidation is still the optimal policy in the two-sector model, it would result in a RER change of

$$\frac{p_{1N}}{p_{2N}} = \frac{z_1}{z_2},$$

which exhibits lower volatility than with liquidation. In other words, the optimal policy helps workers both by reducing the volatility of real wages and the volatility of RER fluctuations.

Additional results for the two-sector model can be obtained by means of numerical techniques. We have confirmed computationally that

- If  $x_T = x_N = x$ , optimal government policy is to employ its reserves to suppress all liquidation. Eliminating liquidation restores the liquidation-is-not-possible equilibrium and this is the optimal policy.
- The optimal subsidy rate in the two sector model is the same as expression (29):
 
$$1 + r^{cb} = \frac{R_2}{x}.$$
- In quantitative examples, capital liquidation raises the volatility of the real exchange rate (RER). Specifically, RER depreciation in a crisis reflects both the decline in TFP and the liquidation of capital.
- In a crisis, international reserves are used to reduce but not eliminate the volatility of the RER. The extent of the intervention depends on amount of capital being liquidated in a crisis and the difference in capital intensities in the two sectors,  $\alpha - \beta$ .
- Quantitatively, the extent of the RER depreciation that reserves policy eliminates is small. Using reserves to limit the damage to the economy from capital liquidation does not limit significantly the extent of RER depreciation, which is driven primarily by the large underlying shock to TFP.

## VII. CONCLUDING REMARKS

This paper analyzed a simple neoclassical model of investment in a developing country, modified to allow for long-term projects and short-term debt. This model generates crises when early signals indicate low productivity of investment. In a crisis, creditors call loans in early and firms protected by limited liability default and liquidate capital in fire sales. We showed that short-term debt financing is beneficial in good (normal) times: when there is no adverse signal, and thus no need to liquidate capital, investment, the capital-labor ratio, wages and *ex post* worker utility are all higher than they would be if liquidation were not possible or was prohibited. Capital liquidation exacerbates the effects of negative shocks by lowering the capital-labor ratio and lowering wages in bad times (crises). Capital liquidation raises the variability of wages and hurts workers who cannot insure against wage income (this seems plausible in emerging market economies). Reserve requirements on debt-generating inflows allow developing countries to accumulate a stock of international reserves that they can use in a crisis can mitigate the adverse effects of capital liquidation on wage variability and worker welfare.

Table 1. Selected Countries: Decline in US Dollar GDP and International Reserves

Country	Year	Decline in \$GDP (in percent)	Ratio Gross Reserves to GDP at end 2007 (in percent)
Argentina	2002	64.0	17.4
Brazil	1999	30.5	13.7
Indonesia	998	55.8	12.8
Kazakhstan	1999	21.6	15.5
Korea	1998	33.9	26.5
Malaysia	1998	27.9	53.4
Mexico	1995	32.0	9.7
Philippines	1998	20.5	21.6
Russia	1998	33.1	34.5
Russia	1999	27.7	34.5
Thailand	1997	17.1	33.6
Thailand	1998	26.0	33.6
Turkey	1994	27.6	10.4
Turkey	2001	27.3	10.4
Ukraine	1998	16.5	22.0
Ukraine	1999	24.6	22.0
Uruguay	2002	34.9	15.1
Memo Item:			
China			47.1

Source: IMF staff calculations.

Table 2. Holdings of International Reserves and Worker Welfare

$g$	$\lambda$	$\psi$	$R/Y$	$U(\gamma=2)$	$Ew$	$CV(w)$ <sup>1</sup>	$U(\gamma=1)$	$U(\gamma=4)$
<b>0</b>	0.0	33.0	0.0	0.0	0.0	0.0	0.0	0.0
<b>1</b>	1.0	31.9	1.1	0.1	0.0	-0.3	0.0	0.5
<b>5</b>	4.8	27.2	5.4	0.7	0.0	-1.2	0.2	2.2
<b>10</b>	9.1	21.4	10.7	1.3	0.0	-2.4	0.3	4.2
<b>15</b>	13.0	15.5	16.0	1.8	0.0	-3.6	0.5	6.1
<b>20</b>	16.7	9.7	21.3	2.3	-0.1	-4.6	0.6	7.8
<b>25</b>	20.0	3.9	26.6	2.7	-0.1	-5.7	0.7	9.4
<b>28.3</b> <sup>2</sup>	22.1	0.0	30.1	3.0	-0.1	-6.3	0.8	10.5

<sup>1</sup> The coefficient of variation of wages is the ratio of the standard deviation to the mean of wages.

<sup>2</sup> This is the maximum permissible value of  $g$ , the reserve requirement on K inflows. This value of  $g$  generates zero capital liquidation in a crisis and is the optimal policy that maximizes workers' expected utility.

**Legend:**  $\psi$  is the fraction of capital being liquidated.  $R/Y$  is the ratio of international reserves to GDP in non-crisis times.  $Ew$  is the expected wage.  $CV(w)$  is the coefficient of variation of wages.  $U$  is the percentage increase in wages that workers must receive in the absence of a reserves policy to make them as well off as they are under the policy. It is the solution  $c$  of the equation  $E\{U(w_1, w_2)\} = E\{U((1+c)w_1, (1+c)w_2)\}$ , where  $(w_1, w_2)$  are wages under the reserves policy and  $(w_{1LF}, w_{2LF})$  are the wages in the absence of policy. Finally,  $\gamma$  is the coefficient of relative risk aversion.

Source: Staff calculations

### APPENDIX I

In an equilibrium with liquidation, the following are true:

$$d = \alpha z_2 A (1-\psi)^{\alpha-1} \left( \frac{K}{L_2} \right)^{\alpha-1} + 1 - \delta = x(1+\bar{r}). \quad (\text{A1})$$

$$d = x(1+\bar{r}) \quad (\text{A2})$$

$$R = z_1 \alpha A \left( \frac{K}{L_2} \right)^{\alpha-1} + 1 - \delta. \quad (\text{A3})$$

Expression (A1) exploits the idea that if the firm engages in both activities (goods production and capital liquidation) then the marginal products of capital in these two activities must be equalized, taking into account timing at international interest rates. To derive (A2) we use equation (10) in the text, the firms's FOC with respect to  $L_2$ , and the fact that default ensures that  $\Pi_2$  is zero, equation (8). In light of (6) and the fact that  $d^f=x$ , we can write (8) as:

$$\Pi_2 = \left\{ Az_2 (1-\psi)^\alpha K^\alpha L_2^{1-\alpha} + x(1+\bar{r})\psi K + (1-\delta)(1-\psi)K - w_2 L_2 - dK \right\}. \quad (\text{A4})$$

Profit per unit of labor is then given by

$$\frac{\Pi_2}{L_2} = \left\{ Az_2 (1-\psi)^\alpha \left( \frac{K}{L_2} \right)^\alpha + x(1+\bar{r})\psi \frac{K}{L_2} + (1-\delta)(1-\psi) \frac{K}{L_2} - w_2 - d \frac{K}{L_2} \right\}. \quad (\text{A5})$$

Using (10) allows us to simplify (A5):

$$\frac{\Pi_2}{L_2} = \alpha Az_2 (1-\psi)^\alpha \left( \frac{K}{L_2} \right)^\alpha + \left\{ x(1+\bar{r})\psi + (1-\delta)(1-\psi) - d \right\} \frac{K}{L_2}. \quad (\text{A6})$$

This can now be rewritten as

$$\frac{\Pi_2}{L_2} = \frac{(1-\psi)K}{L_2} \left\{ \left[ \alpha Az_2 (1-\psi)^{\alpha-1} \left( \frac{K}{L_2} \right)^{\alpha-1} + (1-\delta) \right] + x(1+\bar{r}) \frac{\psi}{1-\psi} - \frac{d}{1-\psi} \right\} = 0. \quad (\text{A7})$$

But in light of (A1), the term in square brackets in the RHS of (A8) equals  $x(1+\bar{r})$ .

Collecting terms and simplifying we have

$$x(1+\bar{r}) \left[ 1 + \frac{\psi}{1-\psi} \right] - \frac{d}{1-\psi} = 0. \quad (\text{A8})$$

which is equivalent to (A2).

The next step is to derive (A3), which is to say that in the limited liability equilibrium, the MPK in the good state equals the return obtained by investors in that state,  $R$ .

Recalling that profit maximization must take into account UIP, the FOC for K is

$$\begin{aligned} 0 = (1-\theta) & \left[ \alpha z_1 A K^{\alpha-1} L_1^{1-\alpha} + 1 - \delta - R - K \frac{\partial R}{\partial K} \right] \\ & + \theta \left[ \alpha z_2 A (1-\psi)^\alpha K^{\alpha-1} L_2^{1-\alpha} + x(1+\bar{r})\psi + (1-\delta)(1-\psi) - d - K \frac{\partial d}{\partial K} \right]. \end{aligned} \quad (\text{A9})$$

To simplify this, note that UIP implies

$$(1-\theta) \frac{\partial R}{\partial K} + \theta \frac{\partial d}{\partial K} = 0. \quad (\text{A10})$$

Hence, the FOC for K can be written as:

$$\begin{aligned} 0 = (1-\theta) & \left[ \alpha z_1 A K^{\alpha-1} L_1^{1-\alpha} + 1 - \delta - R \right] \\ & + \theta \left[ \alpha z_2 A (1-\psi)^\alpha K^{\alpha-1} L_2^{1-\alpha} + x(1+\bar{r})\psi + (1-\delta)(1-\psi) - d \right]. \end{aligned} \quad (\text{A11})$$

But the second expression in square brackets above is zero. To see this, use A1 and A2 again:

$$\begin{aligned} & \left[ \alpha z_2 A (1-\psi)^\alpha K^{\alpha-1} L_2^{1-\alpha} + x(1+\bar{r})\psi + (1-\delta)(1-\psi) - d \right] \\ & = (1-\psi) \left[ \alpha z_2 A (1-\psi)^{\alpha-1} K^{\alpha-1} L_2^{1-\alpha} + x(1+\bar{r}) \frac{\psi}{1-\psi} + 1 - \delta - \frac{d}{1-\psi} \right] \\ & = (1-\psi) \left[ x(1+\bar{r}) + x(1+\bar{r}) \frac{\psi}{1-\psi} - \frac{d}{1-\psi} \right] \\ & = (1-\psi) \left[ x(1+\bar{r}) \left[ 1 + \frac{\psi}{1-\psi} \right] - \frac{d}{1-\psi} \right] = [x(1+\bar{r}) - d] = 0, \end{aligned}$$

which is the desired result.



## APPENDIX II

This Appendix establishes that with log preferences, workers' Expected Utility is higher when liquidation is not possible ( $EU_{NLP} > EU_{LP}$ ) if and only if  $\psi_2 > 0$ , i.e., the amount of liquidation is positive when it is possible.

For EU with liquidation to be lower, we need

$$(1-\theta) \ln \left\{ \frac{(1-\theta)z_1 \alpha A}{\bar{R} - [(1-\theta)(1-\delta) + \theta x(1+\bar{r})]} \right\} + \theta \ln \left\{ \frac{z_2 \alpha A}{x(1+\bar{r}) - (1-\delta)} \right\} < \ln \frac{\alpha A [(1-\theta)z_1 + \theta z_2]}{\bar{R} - (1-\delta)}$$

The above condition is equivalent to

$$(1-\theta) \ln \left\{ \frac{(1-\theta)z_1}{\bar{R} - [(1-\theta)(1-\delta) + \theta x(1+\bar{r})]} \right\} + \theta \ln \left\{ \frac{z_2}{x(1+\bar{r}) - (1-\delta)} \right\} < \ln \frac{(1-\theta)z_1 + \theta z_2}{\bar{R} - (1-\delta)},$$

which can be rewritten as

$$(1-\theta) \ln \left\{ \frac{(1-\theta)}{\bar{R} - [(1-\theta)(1-\delta) + \theta x(1+\bar{r})]} \right\} < \ln \frac{(1-\theta) + \theta(z_2/z_1)}{\bar{R} - (1-\delta)} - \theta \ln \left\{ \frac{z_2/z_1}{x(1+\bar{r}) - (1-\delta)} \right\}.$$

We need to show that

$$\ln \frac{(1-\theta) + \theta Z}{\bar{R} - (1-\delta)} - \theta \ln \left\{ \frac{Z}{x(1+\bar{r}) - (1-\delta)} \right\}$$

increases with  $Z \equiv z_2/z_1$ . We have

$$\frac{d}{dZ} = \theta \left[ \frac{\bar{R} - (1-\delta)}{(1-\theta) + \theta Z} - \frac{x(1+\bar{r}) - (1-\delta)}{Z} \right].$$

Since  $Z < 1$  and  $1+\bar{r} > x \Leftrightarrow \bar{R} > x(1+\bar{r})$ , we have our result.

## APPENDIX III

We use the conditions

$$d = x(1 + \bar{r}) = \beta p_{2N} A_N (1 - \psi_N)^{\beta-1} K_N^{\beta-1} L_{2N}^{1-\beta} + 1 - \delta \quad (\text{A1})$$

and

$$(1 - \alpha) z_2 A_T (1 - \psi_T)^\alpha (K_T / L_T)^\alpha = p_{2N} (1 - \beta) A_N (1 - \psi_N)^\beta (K_N / L_{2N})^\beta (= w_2) \quad (\text{A2})$$

to solve for  $(p_{2N}, \psi_N)$  and prove  $\bar{\psi}_N = \bar{\psi}$ .

$$(1 - \alpha) z_2 A_T (1 - \psi_T)^\alpha (K_T / L_T)^\alpha = p_{2N} (1 - \beta) A_N (1 - \psi_N)^\beta \left( \frac{\beta(1 - \alpha) K_T}{\alpha(1 - \beta) L_T} \right)^\beta$$

$$\Rightarrow p_{2N} = \alpha^\beta (1 - \alpha)^{1-\beta} \beta^{-\beta} (1 - \beta)^{\beta-1} \frac{z_2 A_T (1 - \psi_T)^\alpha}{A_N (1 - \psi_N)^\beta} (K_T / L_T)^{\alpha-\beta}$$

substitute in (A1)

$$x(1 + \bar{r}) - (1 - \delta) = \beta p_{2N} A_N (1 - \psi_N)^{\beta-1} K_N^{\beta-1} L_{2N}^{1-\beta}$$

$\Rightarrow$

$$x(1 + \bar{r}) - (1 - \delta) = \beta A_N (1 - \psi_N)^{\beta-1} K_N^{\beta-1} L_{2N}^{1-\beta} \left[ \alpha^\beta (1 - \alpha)^{1-\beta} \beta^{-\beta} (1 - \beta)^{\beta-1} \frac{z_2 A_T (1 - \psi_T)^\alpha}{A_N (1 - \psi_N)^\beta} (K_T / L_T)^{\alpha-\beta} \right]$$

$\Rightarrow$

$$x(1 + \bar{r}) - (1 - \delta) = \alpha^\beta (1 - \alpha)^{1-\beta} \beta^{1-\beta} (1 - \beta)^{\beta-1} (1 - \psi_N)^{-1} K_N^{\beta-1} L_{2N}^{1-\beta} z_2 A_T (1 - \psi_T)^\alpha (K_T / L_T)^{\alpha-\beta}$$

$\Rightarrow$

$$x(1 + \bar{r}) - (1 - \delta) = \alpha^\beta (1 - \alpha)^{1-\beta} \beta^{1-\beta} (1 - \beta)^{\beta-1} (1 - \psi_N)^{-1} \left[ \frac{\beta(1 - \alpha) K_T}{\alpha(1 - \beta) L_T} \right]^{\beta-1} z_2 A_T (1 - \psi_T)^\alpha (K_T / L_T)^{\alpha-\beta}$$

$\Rightarrow$

$$x(1 + \bar{r}) - (1 - \delta) = \alpha^{\beta-\beta+1} (1 - \alpha)^{1-\beta+\beta-1} \beta^{1-\beta+\beta-1} (1 - \beta)^{\beta-1-\beta+1} (1 - \psi_N)^{-1} z_2 A_T (1 - \psi_T)^\alpha (K_T / L_T)^{\alpha-\beta+\beta-1}$$

$\Rightarrow$

$$x(1 + \bar{r}) - (1 - \delta) = \alpha (1 - \psi_N)^{-1} z_2 A_T (1 - \psi_T)^\alpha (K_T / L_T)^{\alpha-1}$$

$\Rightarrow$

$$x(1 + \bar{r}) - (1 - \delta) = \alpha \frac{1 - \psi_T}{1 - \psi_N} z_2 A_T (1 - \psi_T)^{\alpha-1} (K_T / L_T)^{\alpha-1}$$

$\Rightarrow$

$$\frac{1 - \psi_N}{1 - \psi_T} = \frac{\alpha z_2 A_T (1 - \psi_T)^{\alpha-1} (K_T / L_T)^{\alpha-1}}{x(1 + \bar{r}) - (1 - \delta)}$$

$\Rightarrow$

$$\frac{1-\psi_N}{1-\psi_T} = \frac{\alpha z_2 A_T (1-\psi_T)^{\alpha-1} (K_T / L_T)^{\alpha-1}}{x(1+\bar{r}) - (1-\delta)}$$

But we know from our earlier analysis that

$$(1-\psi_T)(K_T / L_T) = (1-\bar{\psi})\bar{k} = \left\{ \frac{z_2}{z_1} \frac{\alpha A_T (1-\theta) z_1}{x(1+\bar{r}) - [\theta x(1+\bar{r}) + (1-\theta)(1-\delta)]} \right\}^{\frac{1}{1-\alpha}}$$

so

$$\frac{1-\psi_N}{1-\psi_T} = \frac{\alpha z_2 A_T}{x(1+\bar{r}) - (1-\delta)} \frac{z_1}{z_2} \frac{x(1+\bar{r}) - [\theta x(1+\bar{r}) + (1-\theta)(1-\delta)]}{\alpha A_T (1-\theta) z_1}$$

$\Rightarrow$

$$\frac{1-\psi_N}{1-\psi_T} = \frac{x(1+\bar{r}) - [\theta x(1+\bar{r}) + (1-\theta)(1-\delta)]}{(1-\theta)(x(1+\bar{r}) - (1-\delta))}$$

$\Rightarrow$

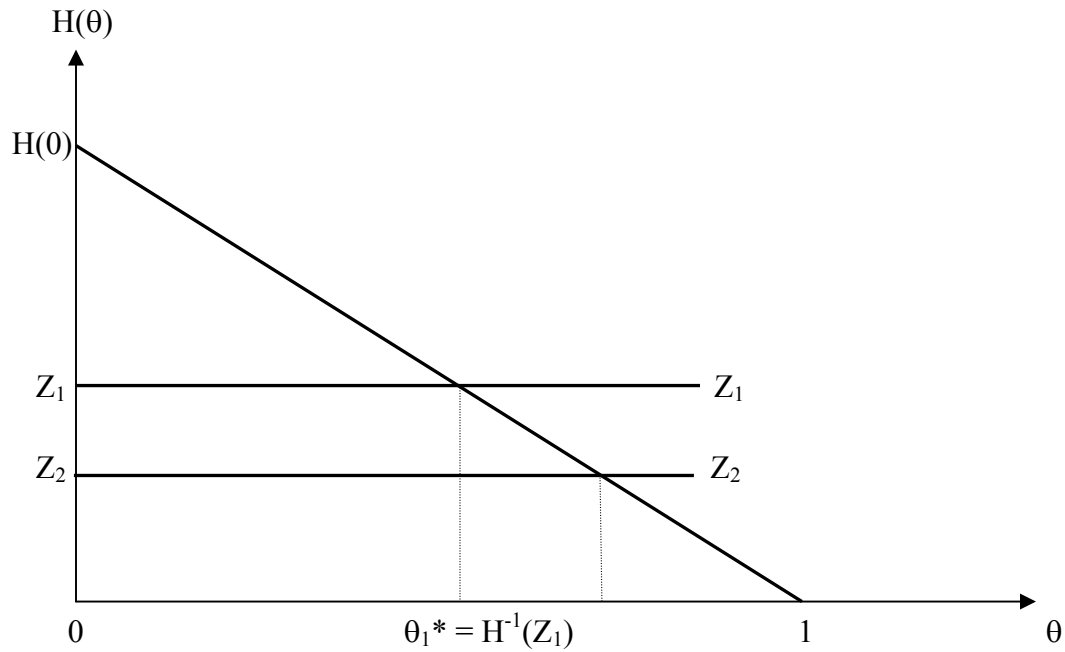
$$\frac{1-\psi_N}{1-\psi_T} = 1$$

$\Rightarrow$

$$\psi_T = \psi_N = \bar{\psi}.$$

In other words, the firm liquidates the same fraction of its capital stock in the two sectors.

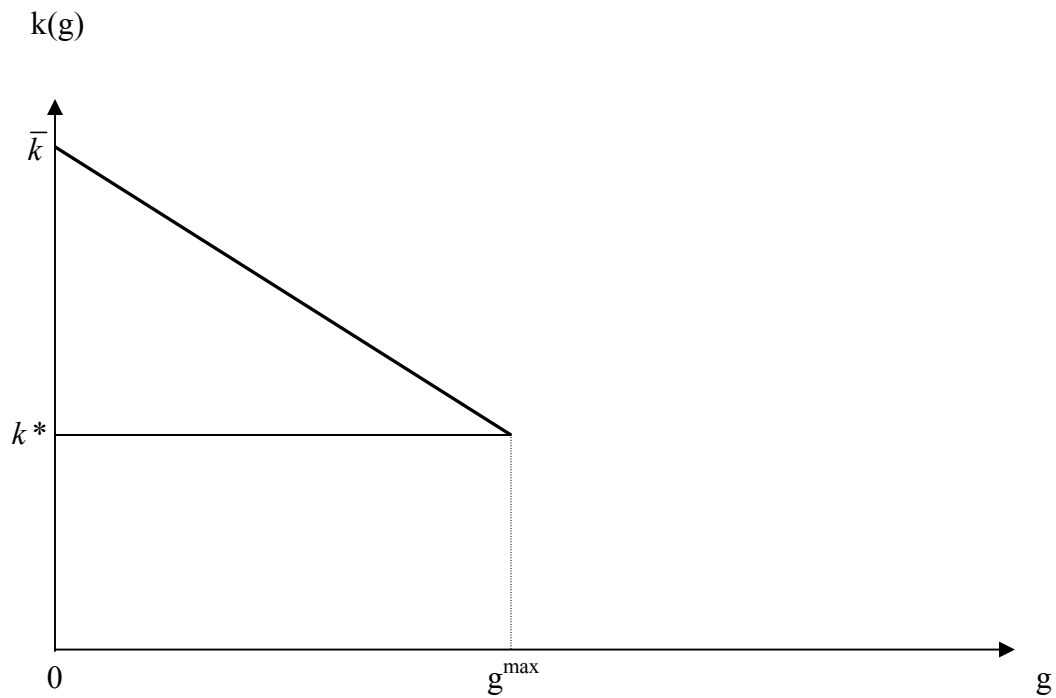
Figure 1. Large and Rare Disasters produce Capital Liquidation



## Legend

- $\theta$  is the probability of the low TFP state. It is bounded between zero and one.
- $Z=z_1/z_2$  is the size of TFP in bad times (crises) relative to good (normal) times. Lower values of  $Z$  indicate more severe disasters.
- Function  $H(\theta)$  was defined in the main text. It is monotonically decreasing in  $\theta$ , starts at  $H(0) = [x(1+\bar{r}) - (1-\delta)] / [\bar{R} - (1-\delta)] > 0$  and declines all the way to  $H(1)=0$ .
- Values of  $Z$  less than  $H(0)$  represent large enough disasters to permit capital liquidation. Given  $Z$ , the probability region for in which capital liquidation will take place is  $(0, \theta^*(Z))$ , where  $\theta^*$  solves  $Z=H(\theta)$ , i.e.,  $\theta^*=H^{-1}(Z)$ .
- In sum, given that disasters are large, they will feature capital liquidation if they are also rare.

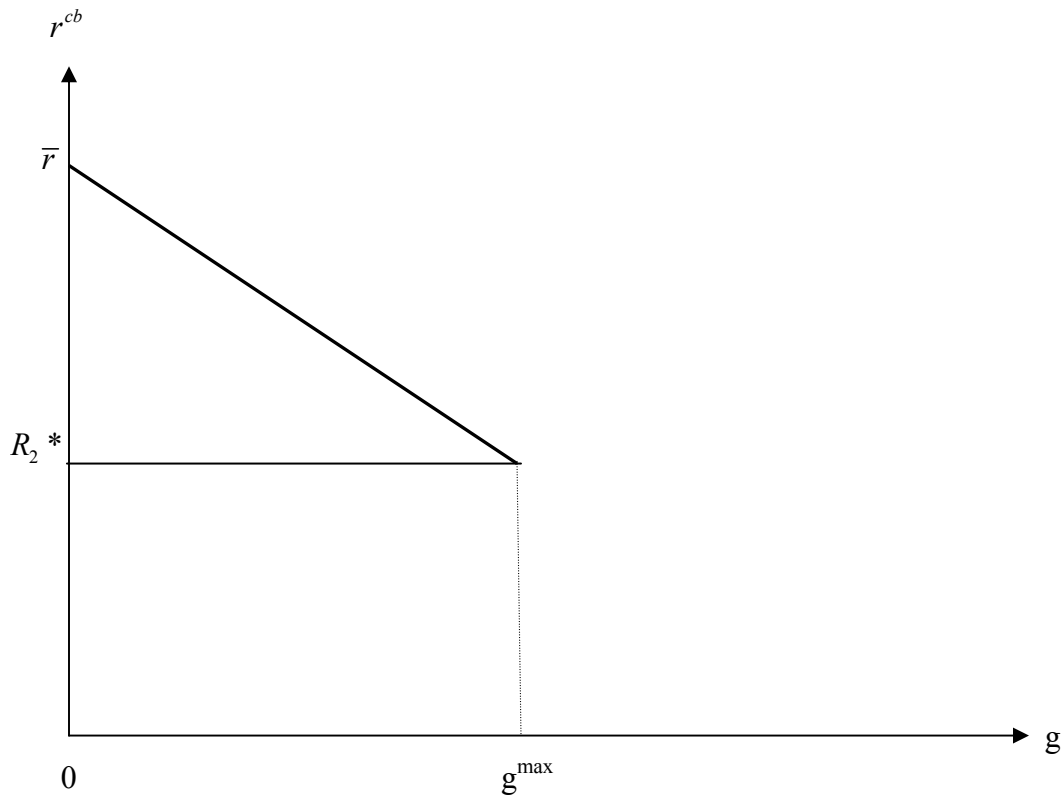
Figure 2. The capital-labor ratio under the Reserve Requirement Scheme



## Legend

- $g$  is the reserve requirement on foreign capital inflows: for every dollar borrowed abroad, domestic banks must deposit a fraction  $g$  with the domestic central bank.
- As the reserve requirement rises, international reserves and emergency central bank lending in a crisis increase, and the extent of capital liquidation declines
- $g^{\max} = x\bar{\nu} / (1 + \bar{r})$  is the highest permissible value of  $g$ . It produces the no-liquidation capital labor ratio  $k^*$ .
- The equilibrium with no liquidation,  $k^*$ , maximizes worker expected utility.

Figure 3. Central Bank Emergency Lending Rates



## Legend

- $r^{cb}$  is the interest rate charged by the central bank on emergency loans to firms that are tied to reductions of capital liquidation.
- For firms to accept these tied emergency loans, they must contain sufficient financial incentives as summarized by the condition  $1 + r^{cb} = R_2 / x$ . As explained in the text, this condition equates the costs and benefits of tied emergency loans and is part of firms' first-order condition for profit maximization with respect to the quantity of emergency loans.
- The interest rate charged by the central bank on its emergency loans declines as the reserve requirement on inflows,  $g$ , rises. The central bank rate tracks the declining the MPK, reflecting growing suppression of liquidation.
- At  $g = g^{\max}$ , all liquidation is suppressed, and the interest rate charged by the central bank is  $R_2^*$ , the gross return to capital in hard times evaluated the no-liquidation capital labor ratio  $k^*$ .

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