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Liquidity Shocks, Banking System Failures, and Supranational Lending of Last Resort Facilities*

Germana Corrado

University of Rome "Tor Vergata", Faculty of Economics
E-mail: corrado@uniroma2.it

In a small open economy with a high share of short term foreign currency denominated debt the arrival of some negative information on banks' investment returns may lead to severe bank runs. We analyse how a supranational institution which acts as an international lender of last resort can cope with banking crises by guaranteeing run-proof bank deposit contracts.

Key Words: Fundamental-based bank runs; Run-proof deposit contracts; International lender of last resort.
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1. INTRODUCTION

The debate on the need for an International Lender of Last Resort (ILOLR) has been reweakened after the recent emerging economies meltdown. Most economies hit by the crisis had external debt denominated in foreign currency. In addition, national lenders of last resort held insufficient reserves to repay all creditors at short notice. It has been argued that the ILOLR function can be viewed as a simple transposition of the closed economy analysis to the global level, since an ILOLR can provide to national central banks the same services that central banks provide to the domestic banking sectors.[1]

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[1] A review of the literature on the lending of last resort function (LOLR) and an analysis on the evolution of the conduct of LOLR interventions both at national and international level are provided by Goodhart and Illing (2002).

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This formal analogy between domestic and international lending of last resort facilities is highlighted by Goodhart and Huang (2000). Their analysis shows that both the fragility of the banking sector and the limited ability of a domestic central bank to provide international liquidity to the interbank market might trigger a banking and a currency crisis. They suggest that an ILOLR can play a useful role in coping with financial crises, and in reducing the international contagion risk in the event of an international illiquidity shortage (see also Chang and Velasco, 1999).

Our work, as most models in this area, is based on the Diamond and Dybvig's (1983) seminal paper on bank runs, but it is also closely related to other studies, in particular to Chari and Jagannathan (1988), Bhattacharya and Jacklin (1988) and Alonso (1996). This strand of literature approaches bank runs through two different types of models. In Diamond and Dybvig's model bank runs occur as sunspots, that is as random phenomena with no correlation with other economic variables.[2] Sunspots are publicly observable extrinsic events that give no information about the underlying economy; nevertheless they can affect the economic fundamentals since agents use them as a coordination device and, thus, they influence agents' beliefs. While Chari and Jagannathan (1988), Bhattacharya and Jacklin (1988), Alonso (1996), Allen and Gale (1998; 2000), among others, describe bank runs using models that emphasize the role of the diffusion among depositors of some negative information on future banks' investment returns.

Following the latter approach, our analysis focuses on information-induced bank runs and shows that when banks own part of their debt in foreign currency these runs can determine a strong reduction in collective welfare (see Chang and Velasco, 2003).

We analyse a small open economy where banking intermediaries' foreign currency denominated debt coupled with the occurrence of some negative information on banks' investment returns may exacerbate the effects of a bank run. In fact, it has been highlighted that the bulk of the 1990s East Asian turmoil was not a pure panic driven widespread banking failure, but a fundamental driven large-scale banking crisis triggered by the weakness of the financial sector. It appeared that Asian vulnerability was created by liberalisation in presence of an underdeveloped bank-based financial system (which contained implicit promises of bailout if its balance sheet deteriorates) and by liberalisation in presence of a monetary policy regime based on pegged exchange rate. These vulnerabilities led to a currency and financial crisis (Corbett and Vines, 1999).

The work also shows how a supranational institution which acts as an ILOLR can effectively and successfully cope with a financial crisis by break-

[2]For a further analysis on banks runs and bank panics see Brunnermeier (2001).

ing the vicious circle linking banking crisis and currency depreciation. Such vicious circle arises when a maturity mismatch is coupled with a currency mismatch in banks' balance sheets (Mishkin, 1999; Jeanne and Wyplosz, 2001). This aspect is crucial since it allows to look at banking and currency fragilities and at their mutually self-reinforcing nature; if fact, as Kaminsky and Reinhart (1999) have pointed out "..financial sector problems undermine the currency. Devaluations, in turn, aggravate the existing banking-sector problems and create new ones. This adverse feedback mechanism can be amplified by banks' inadequate hedging of foreign exchange risk" (p.9).

We analyse how run-proof deposit contracts can be guaranteed by a supranational institution able to provide an elastic supply of funds to the distressed banks in order to avoid systemic bank runs thus leaving to the domestic monetary authorities additional degrees of freedom in the conduct of monetary and exchange rate policy.

The paper is organised as follows. Sections 2 and 3 describe the theoretical model which extends Bhattacharya and Jacklin's paper (1988) on fundamental-based bank runs to an open economy setting. Section 4 provides a numerical exercise. Section 5 focuses on the potential role of a supranational agency able to provide insurance against bank runs. In Section 6 we implement the model by introducing ILOLR facilities and run-proof deposit contracts. Section 7 concludes.

2. THE MODEL

Like in Diamond and Dybvig's (1983) paper, the analysis is based on a three-period model: the planning period ($t = 0$), the intermediate period ($t = 1$) and the final period ($t = 2$). We consider a small open economy populated by a continuum of *ex-ante* identical agents. Each risk averse agent is initially (in $t = 0$) endowed with an amount, e, of a consumption good which is normalized to 1. Consumption preferences are assumed to be identical in $t = 0$ and random over the two dates $t = 1, 2$. This means that *ex-ante* all consumers are identical and are not aware of their types until $t = 1$. This uncertainty is resolved only in $t = 1$ when consumers face a liquidity shock and privately know their type, that is they discover whether they prefer to consume the bulk of their endowment either in $t = 1$ or $t = 2$. Hence, in the interim period agents may become either 'impatient' thus belonging to type 1 consumers, if they value today's consumption more than future consumption, or 'patient' thus belonging to type 2 consumers (in the opposite case). Since the law of large numbers is satisfied and we assume no uncertainty about aggregate consumption needs, then a fraction q of consumers is of type 1 ($j = 1$), and a fraction $1-q$ is of type 2 ($j = 2$). However, individual consumption needs are private information.

Unlike Diamond and Dybvig's model where type 1 agents need to consume in date $t = 1$ and place no value on date $t = 2$ consumption and where type 2 agents do not need liquidity in $t = 1$ and place value on date $t = 2$ consumption, we assume that both types of consumers derive a strictly positive utility from consumption in both periods.

Therefore, consumers' utility functions are defined as:

$$U^1 = u(c_{11}) + \rho_1 u(c_{21}) \quad \text{for a type 1 consumer} \tag{1}$$

$$U^2 = u(c_{12}) + \rho_2 u(c_{22}) \quad \text{for a type 2 consumer} \tag{2}$$

where $u\left(c_{tj}\right)$ denotes type-j consumer's utility in time t, with $t = 1, 2$ and $j = 1, 2$; and $u\left(c_{tj}\right)$ satisfies the following inequalities: $u'(\bullet) > 0$, $u''(\bullet) < 0$. ρ_j is the intertemporal discount factor and the subscript j denotes the type of agent; since impatient agents put more weight on consumption in $t = 1$ and patient agents put more weight on consumption in $t = 2$, then $1 \geq \rho_2 > \rho_1 > 0$. For simplicity, we set $\rho_2 = 1$ and $\rho_1 = \rho < 1$.

• *Banking Intermediaries.* For the sake of simplicity we assume that all the consumers, who also happen to be investors, deposit in $t = 0$ their initial capital endowment in the single representative bank of the economy.[3] The bank can also borrow an amount of money D_f in $t = 0$ from abroad at the foreign interest rate i^* (constant over time) to be repaid in $t = 1$. This assumption captures the idea that banks may turn to be internationally illiquid if their potential short-term obligations in foreign currency exceed the amount of foreign currency they can access in short notice (see Chang and Velasco, 1999).

The banking intermediary pools all the liquidity and makes investments on behalf of private consumers (depositors) in order to maximize the welfare of the representative agent.[4]

Like in Bhattacharya and Jacklin (1988), we assume that there are two investment technologies available to the bank: a deterministic short-lived (storage) technology from $t = 0$ to $t = 1$ that allows for a one-to-one transformation of each unit of consumption, and a long-lived risky illiquid technology from $t = 0$ to $t = 2$ that produces a positive random return in $t = 2$ per unit of investment made in $t = 0$, which gives nothing if early liquidated in $t = 1$.[5] The irreversible bank's investment in long-term asset has a total final random (gross) rate of return, $\tilde{R}$, in $t = 2$ which

[3] As in Diamond and Dybvig's model (1983) we assume that consumers cannot invest directly in the domestic financial market.

[4] We follow Diamond and Dybvig (1983) and other subsequent works, like Bhattacharya and Jacklin (1988) and Chari and Jagannathan (1988), where banks act as mutual banks and thus there is no conflict of interest between depositors and bankers.

[5] We refer to the long run technology as represented by a totally illiquid investment whose irreversibility underscores the cost of early liquidation by 'patient' consumers.

can take two values : $\underline{R}$ which denotes a low return, with unconditional or prior probability p, and $\overline{R}$ which denotes a high return, with unconditional probability $1-p$, where $\overline{R} > 1$ and $0 < \underline{R} < \overline{R}$. Table 1 summarizes the payoff structure of the two technologies per unit of investment.

TABLE 1.

The Bank's Investment Payoffs Structure

Investment projects	$t = 0$	$t = 1$	$t = 2$
Illiquid risky technology (I_r):	-1	0	$\tilde{R} = \left\{ \begin{array}{ll} \overline{R} & \text{Prob } 1-p \\ \underline{R} & \text{Prob } p \end{array} \right\}$
Storage technology (I_f):	-1	$+1$	—

• *The Central Bank.* In this economy there is a Central Bank (CB hereafter) which commits to defend an adjustable pegged exchange rate normalised to 1 in time 0. The exchange rate is subject to devaluation in time 1.

• *Informed depositors.* We assume that in the interim period a fixed fraction α of type 2 depositors receives a signal, s, about the payoff structure of the illiquid risky investment and this signal is identical for all the newly informed depositors. Thus in time $t = 1$ there are some informed 'late liquidity' depositors (or type 2 agents) who update the prior probability of having a low return, $\underline{R}$, from the illiquid technology in $t = 2$ from p to $\hat{p}_s$. With probability τ_1, $\hat{p}_s = \hat{p}_1$, and with probability τ_2, $\hat{p}_s = \hat{p}_2$ where $\hat{p}_1 > \hat{p}_2$; thus $s = 1$ ($s = 2$) denotes the bad (good) signal on bank's long-term investment returns. Also the posterior beliefs on $\tilde{R}$ are consistent with the prior ones, so that the updated probabilities always satisfy the following conditional probability identity $p = \tau_1\hat{p}_1 + \tau_2\hat{p}_2$. Another key assumption is that the banking intermediary designs a standard demand deposit contract that is non-contingent on the signal, s, on the investment return, $\tilde{R}$, received by some patient depositors in the intermediate period. The reason why contractual deposit payoffs in the interim period cannot be conditioned on s is because this information on the future bank's asset return is private; that is, 'interim' information on $\tilde{R}$ is not verifiable even thought some depositors have it. In this situation, when the bank is supposed to use a deposit contract which is unresponsive to the arrival of some new information about $\tilde{R}$, bank runs become a possibility.

• *Uninformed depositors.* Like other works (Bhattacharya and Jacklin, 1988; Alonso, 1996) we assume that depositors are unable to look at each other withdrawals made in $t = 1$; in this way, we rule out 'panic' bank runs *á la* Diamond and Dybvig. Panic bank runs are those driven by the uninformed patient depositors who cannot distinguish at all if the large withdrawals they observe have been made by the informed late liquidity depositors or just by a large proportion of early liquidity depositors.[6] This confounding might mislead uninformed depositors, since what can be observed by each individual is the total amount of withdrawals and not the reason behind their withdrawal decisions (Carletti, 1999). We model bank runs as triggered by fundamentals, that is triggered by some negative information on the returns of the bank's investment returns which has been revealed to a subset of depositors.

2.1. Bank Deposit Contracts

By assumption the bank acts as a mutual fund, thus it pools liquidity and makes investments on behalf of consumers seeking to maximize their welfare by offering an optimal intertemporal risk-sharing through deposit contracts. Bank's portfolio composition and the levels of agents' consumption are derived by maximizing the following expression:[7]

$$\begin{aligned} & \max_{c_{1j}, c_{2j}, I_f, I_r} U\left(c_{1j}, c_{2j}\right) \\ = \; & q\left\{u\left(c_{11}\right) + \rho\left[(1-p)u(\overline{c}_{21}) + pu(\underline{c}_{21})\right]\right\} \\ + \; & (1-q)\left[u\left(c_{12}\right) + (1-p)u(\overline{c}_{22}) + pu(\underline{c}_{22})\right] \quad \text{with } j = 1, 2 \end{aligned} \tag{3}$$

subject to

$$I_f + I_r = e + D_f S_0 \tag{4}$$

$$I_f \geqslant q c_{11} + (1-q) c_{12} + (1+i^*) D_f S_1^e \tag{5}$$

$$\overline{R} I_r \geqslant q \overline{c}_{21} + (1-q)\, \overline{c}_{22} \tag{6}$$

$$\underline{R} I_r \geqslant q \underline{c}_{21} + (1-q)\, \underline{c}_{22} \tag{7}$$

$$u(c_{11}) + p\rho u(\underline{c}_{21}) + (1-p)\rho u(\overline{c}_{21}) \geqslant u\left(c_{12}\right) + p\rho u(\underline{c}_{22}) + (1-p)\rho u(\overline{c}_{22}) \tag{8}$$

$$u(c_{12}) + pu(\underline{c}_{22}) + (1-p)u(\overline{c}_{22}) \geqslant u\left(c_{11}\right) + pu(\underline{c}_{21}) + (1-p)u(\overline{c}_{21}) \tag{9}$$

$$c_{11}, c_{12}, \overline{c}_{22}, \underline{c}_{22}, \overline{c}_{21}, \underline{c}_{21} \geqslant 0 \tag{10}$$

In (3) and (6)-(10) $u\left(\overline{c}_{2j}\right)$ denotes time 2 (higher) consumption associated to $\overline{R}$, while $u(\underline{c}_{2j})$ denotes time 2 (lower) consumption associated to

[6] For example, in Chari and Jagannathan (1988) panic runs may occur because uninformed individuals form their beliefs about the bank's long-term technology according to the size of the withdrawal queue. If the size is large due to a high liquidity shock they may nevertheless infer sufficiently adverse information to precipitate a bank run.

[7] Now we solve the *ex-ante* bank's deposit contract design problem as if no information on the bank's asset quality was perceived by depositors in the intermediate period.

$\underline{R}$. As specified above, we assume that this technology is totally illiquid in the sense that it gives a zero return if it is liquidated prematurely (in $t = 1$). With q we indicate the fraction of type 1 or 'early' consumers, while $(1 - q)$ is the fraction of type 2 or 'late' consumer.

Relationship (4) is the bank's budget constraint and it states that the total amount invested in $t = 0$ by the bank in the short-lived risk free technology, I_f, and in the long-run risky technology, I_r, must be less or equal to the amount deposited by consumers, e, which we set equal to 1, plus the amount of money, D_f, borrowed from abroad. Relationships (5), (6), (7) are the bank's resource balance constraints; they state that the investment returns of the liquid and illiquid assets have to cover agents' consumption needs in time 1 and 2. Constraints (8) and (9) are the usual incentive compatibility constraints for agents of type 1 and type 2 respectively, which ensure that an agent is willing to reveal his type 'truthfully', and no misrepresentation occurs. When constraint (9) is violated, we have a bank run where patient consumers claim to be impatient in time 1, preferring type 2 stream of consumption (c_{12}, c_{22}). In relationships (4) and (5) S_t denotes the nominal exchange rate in time t. We assume that in time $t = 0$, when the deposit contract is offered, there are expectations of domestic currency devaluation in $t = 1$ so that the expected exchange rate in time 1 is $S_1^e > S_0$; since the exchange rate in time 0 is equal to 1, then S_1^e is greater than 1. Under the rational expectation hypothesis $S_1^e = S_1$, thus in $t = 1$ the expected and realised exchange rate levels coincide.

Constraint (5) always holds strictly, otherwise all investments would be liquidated in time 1 and the level of consumption in time 2, c_{2j}, would be equal to zero. Similarly, constraints (6)-(7) must bind if we impose the zero profit condition.

2.2. Solving the Maximization Problem

Consumers' preferences are described by a constant relative risk aversion (CRRA) utility function:

$$u(c_{tj}) = \frac{c_{tj}^{1-\gamma}}{1-\gamma} \tag{11}$$

where $\gamma > 0$ is the constant relative risk aversion coefficient. This functional form for $u(c_{tj})$ is chosen to get closed-form solutions for the consumption levels $c_{11}, c_{12}, c_{21}, c_{22}$.

Thus, by substituting (11) into consumers' utility functions (1) and (2) the expected utility for each type of consumer is:

$$U(c_{11}, c_{21}) = \frac{c_{11}^{1-\gamma}}{1-\gamma} + \rho \frac{c_{21}^{1-\gamma}}{1-\gamma} \quad \text{for 'early' or type 1 consumers} \tag{12}$$

$$U(c_{12}, c_{22}) = \frac{c_{12}^{1-\gamma}}{1-\gamma} + \frac{c_{22}^{1-\gamma}}{1-\gamma} \quad \text{for 'late' or type 2 consumers} \tag{13}$$

PROPOSITION 1. *Given the consumers' preferences functional forms (12) and (13), the maximization problem described by equations (3)-(9) yields the following equalities:*

$$\underline{c}_{22} = (\underline{R}/\overline{R})\bar{c}_{22} \text{ and } \underline{c}_{21} = (\underline{R}/\overline{R})\bar{c}_{21} \tag{14}$$

Proof. See Appendix A ▮

One way to explain (14) is that the consumption levels $\bar{c}_{21}$ and $\bar{c}_{22}$ are the amounts that the bank will be able to repay in the second period only if the long-run investment return is $\overline{R}$. While if $R = \underline{R}$ the bank is considered insolvent and it pays only a fraction $\underline{R}/\overline{R}$ of the promised payments $\bar{c}_{21}$ and $\bar{c}_{22}$. Hereafter, for simplicity of notation, we denote $c_{21} = \bar{c}_{21}$ and $c_{22} = \bar{c}_{22}$ implying:

$$\underline{c}_{22} = (\underline{R}/\overline{R})c_{22} \text{ and } \underline{c}_{21} = (\underline{R}/\overline{R})c_{21} \tag{15}$$

Replacing (15) both in the utility function (3) and in constraints (4)-(9), and setting the nominal exchange rate in $t = 0$ equal to 1, after some manipulations we can restate the bank's maximization problem as follows:

$$\max_{\{c_{1j}, c_{2j}\}} U(c_{1j}, c_{2j})$$
$$= q\left[\frac{c_{11}^{1-\gamma}}{1-\gamma} + \rho K \frac{c_{21}^{1-\gamma}}{1-\gamma}\right] + (1-q)\left[\frac{c_{12}^{1-\gamma}}{1-\gamma} + K\frac{c_{22}^{1-\gamma}}{1-\gamma}\right] \text{with} j = 1, 2 \tag{16}$$

subject to:

$$1 + D_f(1 - (1+i^*)S_1) - q\left(c_{11} + \frac{c_{21}}{\bar{R}}\right) - (1-q)\left(c_{12} + \frac{c_{22}}{\bar{R}}\right) = 0 \tag{17}$$

$$\frac{c_{11}^{1-\gamma}}{1-\gamma} + \rho K \frac{c_{21}^{1-\gamma}}{1-\gamma} - \frac{c_{12}^{1-\gamma}}{1-\gamma} - \rho K \frac{c_{22}^{1-\gamma}}{1-\gamma} \geqslant 0 \tag{18}$$

$$\frac{c_{12}^{1-\gamma}}{1-\gamma} + K \frac{c_{22}^{1-\gamma}}{1-\gamma} - \frac{c_{11}^{1-\gamma}}{1-\gamma} - K \frac{c_{21}^{1-\gamma}}{1-\gamma} \geqslant 0 \tag{19}$$

$$c_{11}, c_{12}, c_{21}, c_{22} \geqslant 0 \tag{20}$$

where $K = (1-p) + p(\underline{R}/\overline{R})^{1-\gamma}$

Type 2 agents' incentive compatibility constraint (19) has the important property that it is never binding in the solution, so in solving the constrained optimization problem it can be considered only type 1 agents' incentive compatibility constraint (18), which binds in the solution. This implies that patient agents strictly prefer type 2 stream of consumption, (c_{12}, c_{22}), to type 1 stream of consumption, (c_{11}, c_{21}), while impatient agents are indifferent between the two allocations.

We then solve analytically the maximization problem to get the consumption levels $c_{11}, c_{12}, c_{21}, c_{22}$ (see Appendix B).

3. INTERIM INFORMATION, BANK RUNS AND CONSUMERS' WELFARE

In this section we reconsider the above utility maximization problem by taking into account the impact of some information on the bank's asset quality which is (asymmetrically) perceived by a subset of late liquidity depositors in $t = 1$ and we show that such information may lead to a bank run. In fact, the arrival of some new information on bank's future investment returns will induce the informed late liquidity depositors to update their prior probability on $\widetilde{R}$ and this in turn will affect the incentive compatibility of the deposit contract. Therefore, with interim information on $\widetilde{R}$ the former incentive compatibility constraint (19) is not sufficient any more to ensure that every type 2 or 'patient' agent will reveal his type truthfully. Whereas constraint (19) is still relevant for the fraction $(1 - \alpha)$ uninformed type 2 agents, it is not sufficient to ensure truthtelling for the fraction α of informed type 2 agents who perceive the signal, so a misrepresentation may occur and the informed late liquidity depositors may start to withdraw in the interim period.

If informed type 2 depositors attempt to withdraw in $t = 1$, the bank might be not able to meet the demand of withdrawals and it will allocate its funds among the depositors according to a first-come first-served scheme. This means that in the intermediate period type 1 and informed type 2 depositors' withdrawals will be randomly allocated in a queue which determines the order in which they are served: the bank will satisfy type 1 withdrawals for a fraction q, after that the bank allows only type 2 withdrawals.

To compute the *ex-ante* utility in presence of interim information on $\widetilde{R}$, we refer to the former utility function as specified in (16), but now we include the updated probability distribution $\hat{p}_s$ over the lower bank's illiquid asset return $\underline{R}$ where $s = 1, 2$ and $\hat{p}_1 > \hat{p}_2$ so $s = 1$ ($s = 2$) denotes the bad (good) signal.

In order to analyze a scenario with bank runs we choose a value of $\hat{p}_1$ above the threshold level $\hat{p}_1^*$, where the latter denotes the lowest *ex-post* (updated) probability on $\underline{R}$ such that the informed type 2 depositors still adhere to the contract. The value of $\hat{p}_1^*$ can be easily computed by considering the value of $\hat{p}_1$ for which the type 2 depositors' incentive compatibility constraint (19) is satisfied with an equality in the solution of problem (16)-(20). Therefore, the 'run' threshold level $\hat{p}_1^*$ can be derived from the following equality:

$$u(c_{12})+\hat{p}_1^* u(\underline{c}_{22})+(1-\hat{p}_1^*)u(\overline{c}_{22}) = u\,(c_{11})+\hat{p}_1^* u(\underline{c}_{21})+(1-\hat{p}_1^*)u(\overline{c}_{21}) \quad (21)$$

that is

$$\hat{p}_1^* = \frac{[u\,(c_{11}) - u(c_{12})] + [u(\overline{c}_{21}) - u(\overline{c}_{22})]}{[u(\underline{c}_{22}) - u(\overline{c}_{22})] - [u(\overline{c}_{21}) - u(\underline{c}_{21})]} \quad (22)$$

or, equivalently, using (14) and (15) and the CRRA utility function (11), we can rewrite (22) as:

$$\hat{p}_1^* = \frac{\left[c_{11}^{1-\gamma} - c_{12}^{1-\gamma}\right] + \left[c_{21}^{1-\gamma} - c_{22}^{1-\gamma}\right]}{\left[1 - (\underline{R}/\overline{R})^{1-\gamma}\right]\left[c_{21}^{1-\gamma} + c_{22}^{1-\gamma}\right]} \quad (23)$$

Above $\hat{p}_1^*$ patient consumers prefer to make type 1 withdrawals and consequently they will precipitate a run on the bank. Hence, if a bad signal has been observed by some late liquidity depositors (or patient consumers) and if $\hat{p}_1 > \hat{p}_1^*$, that is, if the value of the updated probability of a low return from the bank's risky long-lived investment, $\hat{p}$, is greater than the threshold level $\hat{p}_1^*$, then a run occurs. In this event all the early liquidity depositors and the informed late liquidity depositors withdraw money from the bank.

In order to write the collective utility function that takes into account the probability of the signal on the illiquid technology, I_r, we compute the *ex-post* utility levels implied by problem (16)-(18) which now includes the updated probability distribution $\hat{p}_s$.

Following Alonso's work (1996) we denote with $u^j(s,j)$ the *ex-post* utility of a type j consumer who receives the consumption bundle of a type j when the signal s has been revealed, thus the *ex-post* utilities are:

$$u^1(1,j) = u(c_{1j}) + (1-\hat{p}_1)\rho u(\overline{c}_{2j}) + \hat{p}_1 \rho u(\underline{c}_{2j}) \quad \text{for } j = 1,2 \quad (24)$$

$$u^2(1,j) = u(c_{1j}) + (1-\hat{p}_1)u(\overline{c}_{2j}) + \hat{p}_1 u(\underline{c}_{2j}) \quad \text{for } j = 1,2 \quad (25)$$

$$u^1(2) = u(c_{11}) + (1-\hat{p}_2)\rho u(\overline{c}_{21}) + \hat{p}_2 \rho u(\underline{c}_{21}) \quad (26)$$

$$u^2(2) = u(c_{12}) + (1-\hat{p}_2)u(\overline{c}_{22}) + \hat{p}_2 u(\underline{c}_{22}) \quad (27)$$

In (24) $u^1(1,j)$ denotes the *ex-post* utility of type 1 (or early) consumer who receives the consumption bundle intended for type j when $s=1$ (that is, with a bad signal). In (25) $u^2(1,j)$ denotes the *ex-post* utility of type 2 (or late) consumer who receives the consumption bundle intended for type j when $s=1$. In (26) $u^1(2)$ denotes the *ex-post* utility of type 1 consumer when $s=2$ (that is, with a good signal). In (27) $u^2(2)$ denotes the *ex-post* utility of type 2 (late) consumer when $s=2$.

Given the relationship between $\bar{c}_{22}$, $\underline{c}_{22}$ and $\bar{c}_{21}$, $\underline{c}_{21}$ defined in (14) and (15), the *ex-post* utilities reported in (24)-(27) can be rewritten in a more compact form as follows:

$$u^1(1,j) = u(c_{1j}) + K^{'}\rho u(c_{2j}) \quad \text{for } j=1,2 \tag{28}$$

$$u^2(1,j) = u(c_{1j}) + K^{'}u(c_{2j}) \quad \text{for } j=1,2 \tag{29}$$

$$u^1(2) = u(c_{11}) + K^{''}\rho u(c_{21}) \tag{30}$$

$$u^2(2) = u(c_{12}) + K^{''}u(c_{22}) \tag{31}$$

where $K^{'} = (1-\hat{p}_1) + \hat{p}_1(\underline{R}/\overline{R})^{1-\gamma}$ and $K^{''} = (1-\hat{p}_2) + \hat{p}_2(\underline{R}/\overline{R})^{1-\gamma}$.

By using the above *ex-post* utilities levels we can now compute the expected collective utility when a bank run occurs, that is when the updated probability $\hat{p}_1$ over the lower level of return from the illiquid technology, $\underline{R}$, is greater than the run threshold level, $\hat{p}_1^*$, above which the type 2 or patient depositors attempt to make type 1 withdrawals in $t=1$. The *ex-ante* collective utility (16) when a bank run occurs can be then rewritten as follows:

$$\begin{aligned} U(\hat{p}_1 > \hat{p}_1^*) =& q\left[\tau_2 u^1(2) + \tau_1\left(\theta u^1(1,1) + \eta u^1(1,2)\right)\right] \\ &+(1-q)\left[\tau_2 u^2(2) + \tau_1\left(\phi u^2(1,1) + \psi u^2(1,2)\right)\right] \end{aligned} \tag{32}$$

where $\theta = \frac{q}{\alpha(1-q)+q}$ is the probability that in the event of a run a type 1 agent gets a consumption bundle for a type 1 agent; $\eta = \frac{\alpha(1-q)}{\alpha(1-q)+q}$ is the probability that in the event of a run a type 1 agent gets a consumption bundle for a type 2 agent; $\phi = \frac{\alpha q}{\alpha(1-q)+q}$ is the probability that in the event of a run a type 2 agent gets a consumption bundle for a type 1 agent; $\psi = \left(\frac{\alpha^2(1-q)}{\alpha(1-q)+q} + (1-\alpha)\right)$ is the probability that in the event of a run a type 2 agent gets a consumption bundle for a type 2. We have previously denoted with τ_1 the probability that the updated probability distribution over the bank's long-lived investment returns $\hat{p}$ equals $\hat{p}_1$, and with τ_2 the probability that $\hat{p}$ equals $\hat{p}_2$.

4. A NUMERICAL EXERCISE

Given the *ex-ante* collective utility in the event of a run as defined in (32), it is interesting to see how the collective welfare varies in the bad state, that is when a run occurs, through a numerical exercise. In order to make this exercise we should consider the former bank's contract design problem when the expected utility is calculated as a function of the updated probability of having a low bank's investment return, $\hat{p}_1$. We have chosen a value for the updated probability of having a low return from the long-lived technology ($\hat{p}_1$) that is above the threshold level ($\hat{p}_1^*$) beyond which the informed type 2 depositors prefer type 1 depositors' withdrawals. Table 2 gives the parameter values used in the numerical exercise.

TABLE 2.

Parameter values for the numerical exercise

	Case 1	Case 2
γ	0.5	0.5
q	0.5	0.5
ρ	0.3	0.3
α	0.5	0.5
i^*	0.03	0.03
$\overline{R}$	1.5	1.5
$\underline{R}$	1.05	1.05
p	0.2	0.2
$\hat{p}_1$	**0.8***	**0.3**
τ_1	**0.2**	**0.5**
$\hat{p}_2$	**0.05**	**0.1**
τ_2	**0.8**	**0.5**

*Values in bold indicate how the updated probability p̂ varies according to the different informative structure chosen in case 1 and 2 respectively.

In our analysis the worsening of the bank's fundamentals triggers a bank run induced by late liquidity depositors who are 'informed', in the sense that they observe a signal on the bank's illiquid asset return. This signal can be thought of as a leading economic indicator. Although, the signal cannot predict with perfect accuracy the value of $\tilde{R}$ that will be realized in time 2, it allows a subset of agents to update the probability distribution over the returns of the long-run technology and a run may occur.

The banking crisis can be exacerbated in presence of a domestic currency devaluation. In fact, the currency depreciation that in the model occurs in the interim period leads to an increased debt burden which mines the bank's ability to repay. Figure 1 shows the relationship among consumers' utility, the exogenous level of foreign currency denominated short-term bank's debt, D_f, and the expected level of the exchange rate, S_1. It shows that collective welfare sharply decreases as the exchange rate increases (depreciates); in fact, exchange rate fluctuations (here depreciations) worsen bank's balance sheet by increasing the burden of foreign currency denominated debt.

FIG. 1. Consumers' Utility as a Function of the Level of Bank's Foreign Debt, D_f, and of the Nominal Exchange Rate Level, S.

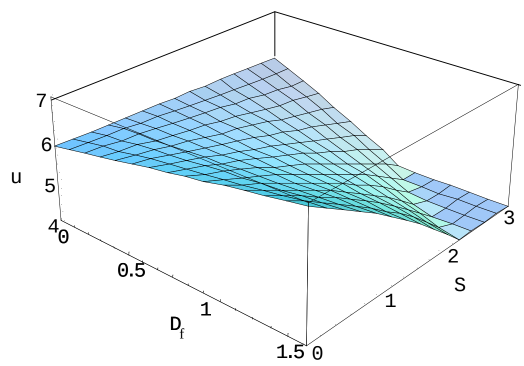


FIG. 2. Impact of Interim Information on Consumers' Utility: Case 1

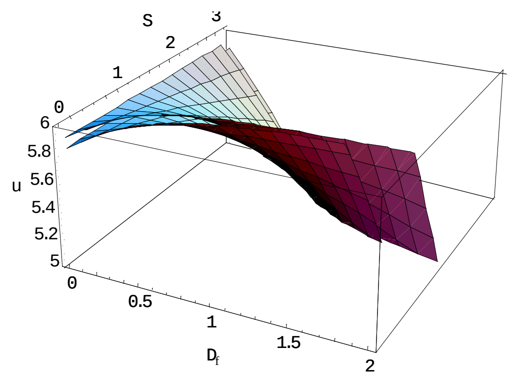
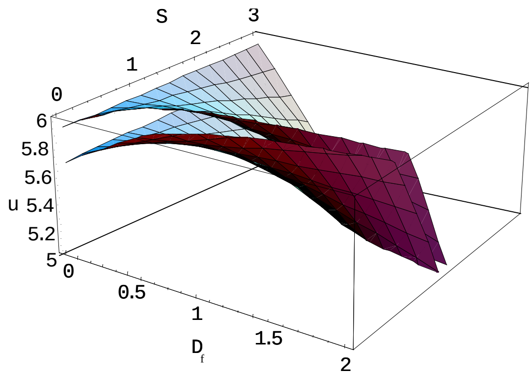


FIG. 3. Impact of Interim Information on Consumers' Utility: Case 2



We then consider two scenarios according to the different informative structure chosen for the bank's long-run investment returns (see in Table 2 the values chosen for $\hat{p}_1$, $\hat{p}_2$, τ_1, τ_2 in case 1 and case 2 respectively). The upper curves in Figure 2 (case 1) and Figure 3 (case 2) represent the collective consumers' utility resulting from the bank's maximization problem described above. The lower curves in the same Figures represent the collective utility when there is a bank run triggered by the arrival of some negative information on bank's future returns. In case 1 (Figure 2) the decrease of the consumers' utility caused by the onset of a bank run is less than in case 2 (Figure 3). In fact, in case 2 the updated probability of having a low return from the long-lived technology ($\hat{p}_1 = 0.3$) is less than in case 1 (where $\hat{p}_1 = 0.8$); nevertheless in case 2 the probability of the realization of the bad signal, $\tau_1 = 0.5$, is greater then in case 1 (where $\tau_1 = 0.2$).

This result is in line with some recent works on financial crises; in fact, as Mishkin (1999) has suggested, in economies with a pegged exchange rate regime one crucial element which can explain the link among banking and currency crises is the fraction of banks' foreign currency denominated liabilities. A devaluation of the domestic currency sharply increases the value of bank's liabilities, thus provoking a further deterioration of banks' balance sheets. In addition, if banks' foreign denominated debt is short-term, the increase in the bank's debt burden may cause liquidity shortages because this debt must be repaid back quickly. In our work the mechanism linking banking and currency crises has been explicitly taken into account in the bank's maximization problem by considering both the banks' foreign currency short-term debt (deposits) and the exchange rate devaluation. In particular the analysis focuses on how currency depreciation worsens the existing banking sector problems if banks have a significative debt exposure in foreign currency without an adequate hedging of the foreign-exchange risk.

This negative feedback effect of the exchange rate market to the banking sector makes the banking problems more difficult to manage by the domestic authorities since they have to deal with a 'twin' crisis, that is a banking and a currency crisis. As the more recent literature has suggested a supranational emergency liquidity lender of last resort could prevent severe large-scale banking failures by supplying the needed international liquidity to the distressed domestic banking intermediaries. This issue will be the focus of the next section.

5. THE LOLR IN AN INTERNATIONAL CONTEXT: AN OVERVIEW OF THE CONTEMPORARY DEBATE

Within the ongoing debate on reforming the international financial architecture, literature is focusing on the potential role of a worldwide agency able to act as a lender of last resort. Some authors have argued that in the last years the IMF is seeming closer to perform as a fully-fledged ILOLR. In fact, through the newly created Supplement Reserve Facility,[8] the IMF seems to have an adequate instrument for handling a crisis. But despite these recently operative changes, it should be put more attention to some aspects that hinder the IMF from acting as an ILOLR, like the absence of full powers of (i) supervisory surveillance, (ii) enforcement and (iii) effective conditionality. All these elements constitute the building blocks on which emergency liquidity support facilities should be set up (Giannini, 1999ab).

In addition, Schwartz (2002) has remarked that the IMF is not and will not be a true LOLR because it cannot print money, therefore since its resources are limited it cannot lend freely against good collateral to a crisis-hit country. But doubts also emerge with regard to the effectiveness of the IMF (limited) lending in resolving crises once they outbreak; and for this reason some authors refer to the IMF and a "quasi" LOLR. Finally another source of critics of the potential role of the IMF as a LOLR for crisis-hit countries emerges from the observation that the IMF should lend against good collateral, but the latter as Eichengreen (2002) pointed out is "..an ill defined concept when the borrower is government instead of a

[8]The Supplement Reserve Facility (SRF) is a special window created in December 1997 and it has been used to provide quickly huge amount of money to countries facing capital account problems (as for Korea, Russia and Brazil hit by external payments crises in the second half of the 1990s). In fact, within the SRF the Contingent Credit Lines have been introduced which allow the IMF to provide large scale financing in case of market contagion.

bank or a firm. A country does not go bankrupt"(p. 58). If the IMF cannot act as a ILOLR, another institution, namely the Federal Reserve, does meet the essential requirements to serve as a fully-fledged ILOLR. The Federal Reserve, unlike the IMF, can create international reserves and acceptable international money (dollars), and it can also create liquidity quickly via open market operations (Keleher, 1999). Robert Mundell (1993) argued that the Federal Reserve role in serving as an ILOLR "...has the power to determine the amount of foreign exchange reserves abroad...In practical sense it is the LOLR to the international banking system, and the determinant of the dollar value of world reserves" (p. 191).

But, it seems that the role of a universal centralized ILOLR is not likely to be embraced neither by the IMF nor by any other institution (like the Federal Reserve) at least in the short-run, so an alternative way to cope with international financial crises has been detected in the provision of regional LOLR services. That is, the emergency liquidity support facilities should be provided by a geographically localized supranational institution to crisis-hit countries belonging to a well-defined and close regional block. The geographical division of the worldwide areas into a system of regional financial agreements should coincide with the current three-block trading configuration. That is Asia, Europe and the Americas each should evolve towards a pattern of relationships for pursuing regional-wide economic integration and financial stability through a set of local common arrangements and institutions.[9] A regional safety net could be a good response to overcome a crisis in a financial system where it is not likely the advent of a universal central bank or an agency acting as fully-fledged LOLR. It thus operates as a first line of defence for the distressed domestic banking and financial systems thanks to its prompter and quicker intervention in the provision of emergency liquidity in the wake of a crisis. In fact, the crises of the late 1990s in Asia, Latin America and Russia have clearly shown that the current international financial system has failed in providing such an effective crisis protection and management mechanisms since, as many observers have argued, once these crises spread across countries the IMF was not be able to adopt measures to stop them (see among others Bello, 1999; Feldstein, 1998; Sachs, 1997; Corbett and Vines, 1999; Higgot and Phillips, 1999; Dieter, 1998). According to this view the implementation of regional agreement for taking measures against the collapse of distressed economies should be a fundamental step towards a more stable international financial market. Such regional safety nets may be defined as a "do it yourself (DIY) LOLR" policy, that serves as a "self-insurance" against liquidity crises (Freixas et al., 1999). Such insurance can be provided in sev-

[9]It has been argued that a system of regional liquidity funds (Asian, American and European) should represent a better solution to manage financial crises (Bergsten, 2000).

eral ways: (i) through the building up of large foreign currency reserves[10]; (ii) the creation of contingent credit facilities with international banks (see Feldstein, 1999); (iii) another approach to the DIY LOLR, in the absence of an effective multilateral international LOLR, is the creation of regional self-insurance funds.[11]

6. THE RUN-PROOF ALLOCATION WITH AN EXTERNAL LOLR INTERVENTION

Now we assume that an external agency can supply an insurance against the bank runs. Although the bank cannot make the deposit contract offered contingent on the signal revealed on long-run returns to depositors, a run proof consumption allocation can be achieved if an external agency can supply an extra amount of liquidity, l, to the patient individuals who withdraw in time 1.[12] Let us consider type 2 agents' incentive compatibility constraint together with the relationship between $\underline{c}_{2j}$ and $\overline{c}_{2j}$ with $j = 1, 2$ as defined in (15). Let us assume that the agency is willing to supply extra liquidity (Proto, 2003) when a negative signal is observed by depositors in $t = 1$ in order to make patient individuals indifferent to the run:

$$\begin{aligned} u(c_{12}) + (1-p)u(c_{22}) + pu\left[\left((\underline{R}/\overline{R}) + l\right) c_{22}\right] &= \\ u\left(c_{11}\right) + (1-p)u(c_{21}) + pu\left[\left((\underline{R}/\overline{R}) + l\right)\right] c_{21} &\quad \text{for } \hat{p} > \hat{p}_1^* \end{aligned} \tag{33}$$

or, using the CRRA utility function (11), we can rewrite the above relationship as:

$$\begin{aligned} & c_{12}^{1-\gamma} + \left[(1-p) + p\left((\underline{R}/\overline{R}) + l\right)^{1-\gamma}\right] c_{22}^{1-\gamma} - c_{11}^{1-\gamma} \\ - \quad & \left[(1-p) + p\left((\underline{R}/\overline{R}) + l\right)^{1-\gamma}\right] c_{21}^{1-\gamma} = 0 \text{ for } \hat{p} > \hat{p}_1^* \end{aligned} \tag{34}$$

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[10]This is just what is currently happening in East Asia where a new era of regionalism seems to be proceeding more rapidly on financial and monetary issues than on trade. For example, the ASEAN+3 -a new regional arrangement with the membership of the ten countries of the ASEAN together with China, Japan and South Korea- has announced a region-wide system of currency swaps which should allow the countries to borrow from each other through swaps of currency reserves.

[11]The initiative for creating an Asian Monetary Fund (AMF) acting as a regional liquidity fund was stopped by the IMF together with the US government in the summer of 1997. But even if this AMF project failed, nevertheless in this region there are plans for implementing a regional liquidity fund.

[12]We are supposing that the external agency analogously to the informed late liquidity agents can observe the signal on bank's investment returns in time.

Thus, for any $\hat{p} > \hat{p}_1^*$ the agency sets l as follows:

$$l(\hat{p}) = \left[\frac{\left(c_{11}^{1-\gamma} - c_{12}^{1-\gamma}\right) - (1-\hat{p})\left(c_{22}^{1-\gamma} - c_{21}^{1-\gamma}\right)}{\hat{p}\left(c_{22}^{1-\gamma} - c_{21}^{1-\gamma}\right)} \right]^{\frac{1}{1-\gamma}} - (\underline{R}/\overline{R}) \text{ for } \hat{p} > \hat{p}_1^* \tag{35}$$

or, equivalently:

$$l(\hat{p}) = \left[\frac{\left(c_{11}^{1-\gamma} - c_{12}^{1-\gamma}\right)}{\hat{p}\left(c_{22}^{1-\gamma} - c_{21}^{1-\gamma}\right)} - \frac{(1-\hat{p})}{\hat{p}} \right]^{\frac{1}{1-\gamma}} - (\underline{R}/\overline{R}) \text{ for } \hat{p} > \hat{p}_1^* \tag{36}$$

We have previously defined $\hat{p}_1^*$ as the lowest *ex-post* probability of a low return such that the informed type 2 depositors still adhere to the contract (that is, for $\hat{p} = \hat{p}_1^*$ type 2 agents' incentive compatibility constraint is satisfied with an equality in the solution problem (16)-(20)). When the updated probability of having a low return from the long-run investment is greater than the threshold level $\hat{p}_1^*$ a run occurs. According to (36) when $\hat{p} > \hat{p}_1^*$ a banking crisis occurs and the agency commits to supply agents some extra money, l, such that the patient agents do not have incentive to run. This deposit contract solves the same problem defined above in (16)-(20) with the additional constraint (33).

If the external agency can observe the signal received by patient agents and makes the amount of emergency liquidity provided contingent on the updated (*ex-post*) probability of having a low return, a run proof consumption allocation can be guaranteed by a deposit contract. The latter mechanism ensures that there will be no misrepresentation -no run- even if the *interim* information is very negative.

7. CONCLUSIONS

Our analysis shows that in open economies a maturity mismatch coupled with a currency mismatch in banks' balance sheets may result in a strong reduction of collective welfare in the event of a bank run. Our analysis suggests that a supranational LOLR might be a viable option to break the vicious circle linking banking and currency crises. We analyse how run-proof deposit contracts can be guaranteed by a supranational institution able to provide an elastic supply of funds to the distressed banks in order to avoid systemic bank runs thus leaving to the domestic monetary authorities additional degrees of freedom in the conduct of monetary and exchange rate policy.

APPENDIX: UTILITY MAXIMIZATION PROBLEM

Given the CRRA utility functions (12)-(13) the consumers' objective function to maximize is:

$$\max U\left(c_{1j}, c_{2j}\right) = \begin{array}{c} q\left[\frac{c_{11}^{1-\gamma}}{1-\gamma} + \rho\left((1-p)\frac{\bar{c}_{21}^{1-\gamma}}{1-\gamma} + p\frac{\underline{c}_{21}^{1-\gamma}}{1-\gamma}\right)\right] + \\ +(1-q)\left[\frac{c_{12}^{1-\gamma}}{1-\gamma} + (1-p)\frac{\bar{c}_{22}^{1-\gamma}}{1-\gamma} + p\frac{\underline{c}_{22}^{1-\gamma}}{1-\gamma}\right] \end{array} \quad \text{with } j = 1, 2 \tag{A.1}$$

And by substituting (5) into relations (6) and (7), the resource balance constraints can be restated as follows:

$$1 + D_f(1-(1+i^*)S_1) = q\left(c_{11} + \frac{\bar{c}_{21}}{\overline{R}}\right) + (1-q)\left(c_{12} + \frac{\bar{c}_{22}}{\overline{R}}\right) \tag{A.2}$$

$$1 + D_f(1-(1+i^*)S_1) = q\left(c_{11} + \frac{\underline{c}_{21}}{\underline{R}}\right) + (1-q)\left(c_{12} + \frac{\underline{c}_{22}}{\underline{R}}\right) \tag{A.3}$$

While under (12)-(13) the incentive compatibility constraints (8) and (9) in the main text can be rewritten as follows

$$\frac{c_{11}^{1-\gamma}}{1-\gamma} + p\rho\frac{\underline{c}_{21}^{1-\gamma}}{1-\gamma} + (1-p)\rho\frac{\bar{c}_{21}^{1-\gamma}}{1-\gamma} \geqslant \frac{c_{12}^{1-\gamma}}{1-\gamma} + p\rho\frac{\underline{c}_{22}^{1-\gamma}}{1-\gamma} + (1-p)\rho\frac{\bar{c}_{22}^{1-\gamma}}{1-\gamma} \tag{A.4}$$

$$\frac{c_{12}^{1-\gamma}}{1-\gamma} + p\frac{\underline{c}_{22}^{1-\gamma}}{1-\gamma} + (1-p)\frac{\bar{c}_{22}^{1-\gamma}}{1-\gamma} \geqslant \frac{c_{11}^{1-\gamma}}{1-\gamma} + p\frac{\underline{c}_{21}^{1-\gamma}}{1-\gamma} + (1-p)\frac{\bar{c}_{21}^{1-\gamma}}{1-\gamma} \tag{A.5}$$

The Lagrangean associated with the optimization problem described by expressions (A.1)-(A.5) is

$$L = \left\{ \begin{array}{c} q \quad \frac{c_{11}^{1-\gamma}}{1-\gamma} + \rho \quad (1-p)\frac{\bar{c}_{21}^{1-\gamma}}{1-\gamma} + p\frac{\underline{c}_{21}^{1-\gamma}}{1-\gamma} \quad + (1-q) \quad \frac{c_{12}^{1-\gamma}}{1-\gamma} + (1-p)\frac{\bar{c}_{22}^{1-\gamma}}{1-\gamma} + p\frac{\underline{c}_{22}^{1-\gamma}}{1-\gamma} \quad + \\ \mu_1 \quad 1 + D_f(1-(1+i^*)S_1) - q \quad c_{11} + \frac{\bar{c}_{21}}{\bar{R}} \quad - (1-q) \quad c_{12} + \frac{\bar{c}_{22}}{\bar{R}} \quad + \\ \mu_2 \left[1 + D_f(1-(1+i^*)S_1) - q \quad c_{11} + \frac{\underline{c}_{21}}{\underline{R}} \quad - (1-q) \quad c_{12} + \frac{\underline{c}_{22}}{\underline{R}} \quad \right] + \\ \mu_3 \quad \frac{c_{11}^{1-\gamma}}{1-\gamma} + p\rho\frac{\underline{c}_{21}^{1-\gamma}}{1-\gamma} + (1-p)\rho\frac{\bar{c}_{21}^{1-\gamma}}{1-\gamma} - \frac{c_{12}^{1-\gamma}}{1-\gamma} - p\rho\frac{\underline{c}_{22}^{1-\gamma}}{1-\gamma} - (1-p)\rho\frac{\bar{c}_{22}^{1-\gamma}}{1-\gamma} \quad + \\ \mu_4 \quad \frac{c_{12}^{1-\gamma}}{1-\gamma} + p\frac{\underline{c}_{22}^{1-\gamma}}{1-\gamma} + (1-p)\frac{\bar{c}_{22}^{1-\gamma}}{1-\gamma} - \frac{c_{11}^{1-\gamma}}{1-\gamma} - p\frac{\underline{c}_{21}^{1-\gamma}}{1-\gamma} - (1-p)\frac{\bar{c}_{21}^{1-\gamma}}{1-\gamma} \end{array} \right\}$$

The first-order conditions (FOCs) are:

$$\frac{\delta L}{\delta c_{11}} = c_{11}^{-\gamma}\left(1 + \frac{\mu_3 - \mu_4}{q}\right) - \mu_1 - \mu_2 = 0 \tag{A.6}$$

$$\frac{\delta L}{\delta c_{12}} = c_{12}^{-\gamma}\left(1 - \frac{\mu_3+\mu_4}{1-q}\right) - \mu_1 - \mu_2 = 0 \tag{A.7}$$

$$\frac{\delta L}{\delta \bar{c}_{21}} = \rho(1-p)\bar{c}_{21}^{-\gamma}\left(1 + \frac{\mu_3-\rho\mu_4}{q}\right) - \frac{\mu_1}{\overline{R}} = 0 \tag{A.8}$$

$$\frac{\delta L}{\delta \underline{c}_{21}} = \rho p\underline{c}_{21}^{-\gamma}\left(1 + \frac{\mu_3-\rho\mu_4}{q}\right) - \frac{\mu_2}{\underline{R}} = 0 \tag{A.9}$$

$$\frac{\delta L}{\delta \bar{c}_{22}} = (1-p)\bar{c}_{22}^{-\gamma}\left(1 - \frac{\rho\mu_3+\mu_4}{1-q}\right) - \frac{\mu_1}{\overline{R}} = 0 \tag{A.10}$$

$$\frac{\delta L}{\delta \underline{c}_{22}} = p\underline{c}_{22}^{-\gamma}\left(1 - \frac{\rho\mu_3+\mu_4}{1-q}\right) - \frac{\mu_2}{\underline{R}} = 0 \tag{A.11}$$

$$\frac{\delta L}{\delta \mu_1} = 1 + D_f(1-(1+i^*)S_1) - q\left(c_{11} + \frac{\bar{c}_{21}}{\overline{R}}\right) - (1-q)\left(c_{12} + \frac{\bar{c}_{22}}{\overline{R}}\right) = 0 \tag{A.12}$$

$$\frac{\delta L}{\delta \mu_2} = 1 + D_f(1-(1+i^*)S_1) - q\left(c_{11} + \frac{\underline{c}_{21}}{\underline{R}}\right) - (1-q)\left(c_{12} + \frac{\underline{c}_{22}}{\underline{R}}\right) = 0 \tag{A.13}$$

$$\mu_3\frac{\delta L}{\delta \mu_3} = \frac{c_{11}^{1-\gamma}}{1-\gamma} + p\rho\frac{\underline{c}_{21}^{1-\gamma}}{1-\gamma} + (1-p)\rho\frac{\bar{c}_{21}^{1-\gamma}}{1-\gamma} - \frac{c_{12}^{1-\gamma}}{1-\gamma} - p\rho\frac{\underline{c}_{22}^{1-\gamma}}{1-\gamma} - (1-p)\rho\frac{\bar{c}_{22}^{1-\gamma}}{1-\gamma} = 0 \tag{A.14}$$

$$\mu_4\frac{\delta L}{\delta \mu_4} = \frac{c_{12}^{1-\gamma}}{1-\gamma} + p\frac{\underline{c}_{22}^{1-\gamma}}{1-\gamma} + (1-p)\frac{\bar{c}_{22}^{1-\gamma}}{1-\gamma} - \frac{c_{11}^{1-\gamma}}{1-\gamma} - p\frac{\underline{c}_{21}^{1-\gamma}}{1-\gamma} - (1-p)\frac{\bar{c}_{21}^{1-\gamma}}{1-\gamma} = 0 \tag{A.15}$$

where $\mu_1, \mu_2 > 0$ and $\mu_3, \mu_4 \geqslant 0$ are respectively the Lagrange multipliers of constraints (A.2),(A.3) and (A.4),(A.5).

From (A.8) and (A.10) we get:

$$\bar{c}_{21} = \rho^{1/\gamma}\frac{\left(1+\frac{\mu_3-\mu_4}{q}\right)^{1/\gamma}}{\left(1-\frac{\rho\mu_3+\mu_4}{1-q}\right)^{1/\gamma}}\bar{c}_{22} \tag{A.16}$$

From (A.9) and (A.11) we have:

$$\underline{c}_{21} = \rho^{1/\gamma}\frac{\left(1+\frac{\mu_3-\rho\mu_4}{q}\right)^{1/\gamma}}{\left(1-\frac{\rho\mu_3+\mu_4}{1-q}\right)^{1/\gamma}}\underline{c}_{22} \tag{A.17}$$

From the resource balance constraints (A.12) and (A.13) we get:

$$q\frac{\bar{c}_{21}}{\bar{R}} + (1-q)\frac{\bar{c}_{22}}{\bar{R}} = q\frac{\underline{c}_{21}}{\underline{R}} + (1-q)\frac{\underline{c}_{22}}{\underline{R}} \tag{A.18}$$

Substituting (A.16)and (A.17) into (A.18) yields:

$$\begin{aligned} & q\rho^{1/\gamma}\frac{\left(1+\frac{\mu_3-\mu_4}{q}\right)^{1/\gamma}}{\left(1-\frac{\rho\mu_3+\mu_4}{1-q}\right)^{1/\gamma}}\frac{\bar{c}_{22}}{\bar{R}} + (1-q)\frac{\bar{c}_{22}}{\bar{R}} \\ = & q\rho^{1/\gamma}\frac{\left(1+\frac{\mu_3-\mu_4}{q}\right)^{1/\gamma}}{\left(1-\frac{\rho\mu_3+\mu_4}{1-q}\right)^{1/\gamma}}\frac{\underline{c}_{22}}{\underline{R}} + (1-q)\frac{\underline{c}_{22}}{\underline{R}} \end{aligned} \tag{A.19}$$

From (A.19) we derive the following equalities:

$$\underline{c}_{22} = (\underline{R}/\overline{R})\bar{c}_{22}, \text{ and similarly } \underline{c}_{21} = (\underline{R}/\overline{R})\bar{c}_{21} \tag{A.20}$$

APPENDIX: THE OPTIMALITY CONDITIONS

As type 2 consumers' incentive compatibility constraint does not bind in the solution of the single constrained maximization problem, the Lagrange multiplier associated with the incentive compatibility constraint (19) will be equal to zero. It is then necessary to consider only type 1 consumers' incentive compatibility constraint (18) in solving the optimization problem.

The Lagrangean associated with the constrained optimization problem described by (16)-(18) is:

$$L = \left\{ \begin{array}{c} 1/(1-\gamma)q\left[c_{11}^{1-\gamma} + \rho K c_{21}^{1-\gamma}\right] + 1/(1-\gamma)(1-q)\left[c_{12}^{1-\gamma} + K c_{22}^{1-\gamma}\right] + \\ z_1\left[1 + D_f(1-(1+i^*)S_1) - q\left(c_{11} + \frac{c_{21}}{\bar{R}}\right) - (1-q)\left(c_{12} + \frac{c_{22}}{\bar{R}}\right)\right] + \\ z_2\left[1/(1-\gamma)(c_{11}^{1-\gamma} + \rho K c_{21}^{1-\gamma} - c_{12}^{1-\gamma} - \rho K c_{22}^{1-\gamma})\right] \end{array} \right\}$$

where $K = (1-p) + p(\underline{R}/\overline{R})^{1-\gamma}$

The FOCs are:

$$\frac{\delta L}{\delta c_{11}} = c_{11}^{-\gamma}\left(1 + \frac{z_2}{q}\right) - z_1 = 0 \tag{B.1}$$

$$\frac{\delta L}{\delta c_{12}} = c_{12}^{-\gamma}\left(1 - \frac{z_2}{1-q}\right) - z_1 = 0 \tag{B.2}$$

$$\frac{\delta L}{\delta c_{21}} = \rho K c_{21}^{-\gamma}\left(1+\frac{z_2}{q}\right) - \frac{z_1}{\bar{R}} = 0 \tag{B.3}$$

$$\frac{\delta L}{\delta c_{22}} = K c_{22}^{-\gamma}\left(1-\frac{\rho z_2}{1-q}\right) - \frac{z_1}{\bar{R}} = 0 \tag{B.4}$$

$$\frac{\delta L}{\delta z_1} = 1+D_f(1-(1+i^*)S_1)-q\left(c_{11}+\frac{c_{21}}{\bar{R}}\right)-(1-q)\left(c_{12}+\frac{c_{22}}{\bar{R}}\right) = 0 \tag{B.5}$$

$$\frac{\delta L}{\delta z_2} = c_{11}^{1-\gamma} + \rho K c_{21}^{1-\gamma} - c_{12}^{1-\gamma} - \rho K c_{22}^{1-\gamma} = 0 \tag{B.6}$$

where $z_{1,}\ z_2 > 0$ are the Lagrange multipliers associated with constraints (17) and (18) respectively.

The consumption levels $c_{11}, c_{12}, c_{21}, c_{22}$ are obtained by solving the following system of equations:

$$c_{11} = \left[\frac{1}{z_1}\left(1+\frac{z_2}{q}\right)\right]^{1/\gamma} \tag{B.7}$$

$$c_{12} = \left[\frac{1}{z_1}\left(1-\frac{z_2}{1-q}\right)\right]^{1/\gamma} \tag{B.8}$$

$$c_{21} = \left[\frac{1}{z_1}\rho K\bar{R}\left(1+\frac{z_2}{q}\right)\right]^{1/\gamma} \tag{B.9}$$

$$c_{22} = \left[\frac{1}{z_1}K\bar{R}\left(1-\frac{\rho z_2}{1-q}\right)\right]^{1/\gamma} \tag{B.10}$$

$$\begin{aligned}&\left(1+\frac{z_2}{q}\right)^{\frac{(1-\gamma)}{\gamma}} + \rho K\left[\rho K\bar{R}\left(1+\frac{z_2}{q}\right)\right]^{\frac{(1-\gamma)}{\gamma}} \\ &-\left(1-\frac{z_2}{1-q}\right)^{\frac{(1-\gamma)}{\gamma}} - \rho K\left[K\bar{R}\left(1-\frac{\rho z_2}{1-q}\right)\right]^{\frac{(1-\gamma)}{\gamma}} = 0\end{aligned} \tag{B.11}$$

$$\begin{aligned}&1+D_f(1-(1+i^*)S_1) - \frac{q}{z_1^{1/\gamma}}\left(1+\frac{z_2}{q}\right)^{1/\gamma}\left(1+\left(\rho K\bar{R}^{(1-\gamma)}\right)^{1/\gamma}\right) \\ &-\frac{(1-q)}{z_1^{1/\gamma}}\left[\left(1-\frac{z_2}{1-q}\right)^{1/\gamma} + \left(K\bar{R}^{(1-\gamma)}\left(1-\frac{\rho z_2}{1-q}\right)\right)^{1/\gamma}\right] = 0\end{aligned} \tag{B.12}$$

From (B.7)-(B.12) we get:

$$c_{11} = \frac{H^2 A}{q^2 B} \tag{B.13}$$

$$c_{21} = \left(\rho K \bar{R}\right)^2 c_{11} \tag{B.14}$$

$$c_{12} = \left[\frac{(1-2q+H)\,q}{(1-q)\,H}\right]^2 c_{11} \tag{B.15}$$

$$c_{22} = \left[\frac{K\bar{R}q\,(H-1)}{(1-q)\,H}\right]^2 c_{11} \tag{B.16}$$

where

$$\begin{aligned} H &= q + (1-q)\,q\bar{R}\rho\,(1-\rho) \\ A &= d(S(1+i^*)-1)-1 \\ B &= -1 + (1-q)\,q\bar{R}\rho\,(1-\rho)\left[\bar{R}(\rho-1)\rho-4\right] + \\ & \quad K^2\bar{R}\left\{-1+q\,(1-\rho)\,[1-\rho(-1+\bar{R}\rho(1-q)\,(1-\rho)\,(\bar{R}\rho^2-2))]\right\} \end{aligned}$$

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