ESSAYS ON BANKING

AND

FOREIGN EXCHANGE MARKET

INSTABILITY

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To my parents

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Abstract

Financial intermediation has been associated with several risks. We study sunspot panics, information-based bank runs, contagion, uncertainty about consumption time preference, twin crises and a number of policies attempting to resolve these issues.

We offer a basic model where sunspot panics and information-based bank runs co-exist. This framework can be used to evaluate a number of policies. We examine closely the policy of suspension of deposit convertibility and observe a trade-off regarding its implementation. Although suspension eliminates sunspot panics, it presents important drawbacks in an environment vulnerable to information-based bank runs, thus generating a dilemma for policy makers. It removes the advantage of discretionary liquidation of long-term technologies when portfolio returns are expected to be extremely low, and eliminates the signalling property of suspension that continuation of investment is beneficial, which can mitigate the spread of contagion. We offer an alternative solution, with discretionary rules accounting for every possible state of the economy.

Studying uncertainty about consumption time preference, we demonstrate that partial suspension is welfare improving on

the outcome of full suspension. Nevertheless, in the absence of limitations preventing the formation or the efficient operation of an inter-bank market, borrowing and lending among intermediaries will be the optimal solution. In demonstrating this, we make sure we respect the sequential service constraint that necessitates redemption obligations to be honoured in a first-come first-served basis.

Opening up the economy, by the addition of a foreign exchange market and by assuming a fixed exchange rate regime, we study the possibility of twin crises. We abstract from foreign capital as the source of instability and focus on the role of domestic depositors. Speculative opportunities in the currency markets can result in banking crises, while banking crises can lead to betting against the exchange rate regime. Suspension of convertibility can limit funds for speculation, but at the expense of depositors' welfare, thus raising a dilemma for policy makers.

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CHAPTER 1

Introduction

What is the role of an intermediary? Financial intermediaries undertake a number of functions. One of the views on why intermediaries exist emphasises the existence of transaction costs and market imperfections in information gathering and portfolio management. Due to economies of scale, a financial intermediary enjoys a comparative advantage in information technology investing, which allows efficient differentiation among risk and return diverse projects and monitoring during the stages of the projects' implementation. If this was not the case, everyone would manage his own portfolio as efficiently as the existing professional portfolio managers.

A second role for intermediaries is in managing risks and providing insurance to risk averse individuals. Often, people facing uncertainty like to trade part or all of the riskiness attached to unwanted outcomes for the utility equivalent expected income, even if this is lower in expected nominal terms. This implies that financial intermediaries performing this function have to manage the accepted risk efficiently in order to honour their contracts.

But perhaps the most important function of intermediation is that of liquidity transformation. This involves transforming securities of short maturities, preferred by lenders, into securities of long maturities, preferred by borrowers. Consider banks that issue liabilities at low yields to facilitate the liquidity needs of depositors. Part of the funds is invested in low yielding liquid assets, to facilitate the early liquidity needs of depositors, and part is invested in high yielding illiquid assets, for their later needs.

Why do financial crises take place? Attempting to answer this question, let us break down the problem of crises in three sub-cases. First we consider crises in the banking sector, then in the foreign currency sector and finally twin crises that combine the two individual types.

A combination of the conditions and services justifying financial intermediation can be used to explain *banking crises*, phenomena that have dominated banking history indiscriminately of geographic or epoch differences. The work of Sprague (1910) on the US National Banking System from 1873 to 1907, Friedman and Schwartz (1963) on the US from 1867 to 1960, Demirgüç-Kunt and Detragiache (1998) studying 45 to 60 countries from

1980 to 1994 or Glick and Hutchison (1999) studying 90 countries from 1975 to 1997 are only but a few examples portraying the diversity of banking sector failures.

The seminal work of Diamond and Dybvig (1983) provides a framework to work with. Consider depositors that require insurance against uncertainty over consumption timing, in an environment where investment opportunities are illiquid. Assume that imperfect information makes their idiosyncratic consumption preference unobservable to third parties. Then, a role for banks arises in insuring depositors against their liquidity risk, by transforming part of the deposit funds into illiquid investments. However, intermediation is subject to risk, since part of the bank's assets will be illiquid and promised allocations can only be made contingent on the stated and not necessarily true liquidity need of the individual depositor.

Fear of insolvency can be self-fulfilling, providing an explanation for the existence of banking failures. If an exogenous event (sunspot) can co-ordinate the actions of depositors in withdrawing prematurely, before their consumption need arises, fire-sale prices from the premature liquidation of the bank's illiquid assets and the first-come first-served nature of banking justify the decision to run and, consequently, the failure of banks.

Nevertheless, it is precisely this unpredictable nature of the panic view of bank failures in the Diamond and Dybvig model that has received the most scrutiny over the years. From an empirical point of view Gorton's (1988) study of the US National Banking Era, followed by a number of other researches on the US banking sector, and Demirgüç-Kunt and Detragiache (1998) studying a large sample of countries in the period 1980-1994 offer a convincing case against sunspot theory as an explanation of banking crises. From the theoretical point of view the inclusion of interim information regarding banks' portfolios has produced two effects. Goldstein and Pauzner (2000), following the work of Morris and Shin (1998) in currency crises, demonstrate how noisy information signals and uncertainty over other agents' actions can resolve the indeterminacy of multiple equilibria, leading to a unique outcome. And Jacklin and Bhattacharya (1988) demonstrate how interim information regarding the future state of a bank's assets, will lead to information-based bank runs if early withdrawal results to higher utility in comparison to low future consumption from a bad performing bank portfolio.

Given the on-going controversy regarding the nature of bank failures, what recommendation can we make for policy makers? Unfortunately, policy related research has concentrated on either sunspot panics or information-based bank runs. The basic model of Chapter 3 tries to deal with this void in the literature. We construct a simple framework that is subject to both types of failures, and in Chapter 4 we examine whether and how a policy of suspension of deposit convertibility should be implemented in such an environment.

Suspension of convertibility has traditionally trailed serious problems in the banking sector. Sprague (1910) and Friedman and Schwartz (1963) note as many as nine suspensions at the national or state level in the US between 1814 and 1933. A more recent example is that of Argentina announcing a partial, followed by full suspension in 2001, with significant consequences for depositors' welfare, resulting in domestic riots and regional contagion spreading to Uruguay and Brazil.

It is an interesting policy because it is subject to a trade-off in the presence of sunspot panics and information-based runs. On the one hand, its ex-ante announcement can eliminate jumps between multiple equilibria, allowing only for the Pareto optimal bank state. Nevertheless, it may do so at a great cost if information-based bank runs prevail in the system. In that case suspension denies the possibility of premature liquidation, which may be an efficient alternative to bad performing assets. Furthermore, it eliminates the signalling property of suspension of convertibility to the depositors of banks beside the troubled ones, which reveals that the economy is not in such a bad state as they may have originally anticipated. Given this dilemma, we suggest that the best option for a policy maker is to express rules that cover every possibility. If suspension is implemented in every case except when the troubled banks portfolios are dominated by liquidation, then sunspots are eliminated and the good properties of discretion with regard to information-based bank runs remain present.

In our study of suspension of convertibility we explore another interesting research area of banking crises, namely contagion. We note that the literature has mainly concentrated in the role of interbank markets as the link justifying the spread of crisis, with a few notable exceptions. This observation and the empirical research suggesting informational updates as a central feature of contagion in the banking sector (an example being Aharony and Swary (1996)) motivate our choice of information as the propagation mechanism of crises.

Nevertheless, suspension of convertibility may be useless in the presence of aggregate uncertainty over consumption timing. If the intermediary is unable to predict the aggregate number of early consumers, suspension may prevent closure of the troubled bank, but will result in over- or under-estimation of storage in the planning period with dear consequences for the efficiency of the system and depositors' utility. We show in Chapter 5, expanding the work of Wallace (1988) in a richer environment where the main addition is to take illiquidity of the productive technologies seriously, that partial suspension may be welfare improving relative to full suspension. But the optimal solution in this environment is that of an interbank mechanism with borrowing and lending among banks. We follow the general framework of Bhattacharya and Gale (1987) in exploring interbank co-operation, but for one objection to their work. Accepting that the sequential service constraint is a feature of banking contracts implies that contracts cannot be made contingent on the mass of withdrawals. In interbank market contracts this translates in common early consumption allocation promises made by all participating banks, which is part of our modelling but not a feature of the Bhattacharya and Gale contracting approach.

Returning to our original question of why do financial crises take place, let us move on to *foreign currency market crises*. Similarly to banking sector crises, two explanations emerged to account for speculative attacks against exchange rate pegging. One has its roots in policy inconsistencies (Krugman (1979)), while the other blames sudden shifts in market expectations and multiple equilibria (Obstfeld (1986)). The former relates to crises in Latin American countries in the 1980s, while the latter is best applied to the UK experience with the Exchange Rate Mechanism (ERM) of the European Monetary System (EMS) in 1992.

The East Asian crisis of mid-1997, that was unpredicted by the existing models of crises, and the empirical work of Kaminsky and Reinhart (1999), finding a strong link between banking and currency crises, sparked vigorous research on twin crises. The research concentrated on foreign investors participating in domestic technologies through domestic banks or domestic banks short-term borrowing from abroad. In Chapter 6, contrary to the existing literature that relies on forms of foreign inflows in order to explain twin crises, we turn our attention to the domestic depositor and the possible causation links between crises in the two financial sectors. We show that a strong banking sector may come under attack if speculators use their deposits to take advantage of opportunities in the foreign currency markets. Furthermore, a domestic bank run, driven by the weak performance of banks' portfolios, leaves speculators with assets that they may employ in an attack against the peg, which may not be subsequently successfully defended by the government, thus leading to a currency crisis. Suspension of convertibility presents a dilemma in this environment, assuming policy makers are sensitive to depositors' welfare. On the one hand the policy reduces the available funds for speculation in the foreign exchange market, while on the other hand it decreases consumption and thus depositors' welfare.

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CHAPTER 2

Literature Review

2.1 Banking Crises: Overview

"A banking panic occurs when bank debt holders at all or many banks in the banking system suddenly demand that banks convert their debt claims into cash (at par) to such an extend that the banks suspend convertibility of the debt into cash or...act collectively to avoid suspension of convertibility by issuing clearing-house loan certificates".[1] In this Section, we review the research that has modified and extended the seminal contribution of Diamond and Dybvig (1983) on the role of banks and on banking crises.[2]

The model of Diamond and Dybvig demonstrates the role of optimal liquidity provision by banks, which nevertheless

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[1] Calomiris and Gorton (1991), p. 112.

[2] In depth discussions of the theory of bank runs are provided by Calomiris and Gorton (1991), Bhattacharya and Thakor (1993). Systemic

generates bank failures due to multiple equilibria. A good equilibrium is associated with optimal insurance against depositors' idiosyncratic liquidity shocks, while a bad equilibrium is the result of panic from fear of excess withdrawals resulting in the premature liquidation of productive investments.

We discuss the interesting, yet sometimes contradicting, policy recommendations suggested by Diamond and Dybvig for eliminating the Pareto dominated equilibrium. Suspension of convertibility is a mechanism that avoids panics in the two-period framework of Diamond and Dybvig, yet may not do so given more periods. It may act as a signal that a bank's portfolio is in a good state, thus preventing bank runs, yet it may destroy the demandable debt property of deposit contracts, which provides incentive compatible intermediation.

Given aggregate uncertainty over consumption timing, the optimality of suspension of convertibility in eliminating the bad equilibrium is lost, and Diamond and Dybvig recommend a form of wealth redistribution associated with the policy of deposit insurance. After reviewing the work that has been done to justify the existence of the first-come first-served property of banking contracts, we discuss how the sequential service constraint prevents the implementation of deposit insurance and look at

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risk is discussed by Eisenbeis (1997), and bank regulation by Bhattacharya, Boot and Thakor (1998).

alternative solutions, like partial suspension of convertibility and interbank co-ordination.

We then contrast the Diamond and Dybvig model of sunspot panics with frameworks, like that of Jacklin and Bhattacharya (1988), where information-based bank runs are responsible for banking failures. We take a look at objections raised with regard to the use of multiple equilibria as a possible explanation of bank failures and explore alternatives, like the panic aspect of interim information over banks' portfolios.

Inter-bank markets and interim information also drive studies of contagion in the banking sector, which we review before considering the empirical evidence on banking failures. We pay particular attention on the controversy over the cause of failures, more specifically whether they are the result of unpredictable panics or deteriorating returns of bank held assets.

2.1.1 Sunspot Panics

The influential work of Diamond and Dybvig (1983), following Bryant (1980), presented a microeconomic framework that illustrated two properties of the banking sector. Diamond and Dybvig demonstrated that bank deposit contracts can be optimal, matching maturity between assets and liabilities and providing insurance to depositors against liquidity risks, but nevertheless lead to banking panics.

Depositors are, ex-ante, uncertain about preferences over consumption periods. At the same time they face an environment in which long-term investments are highly productive, yet costly to liquidate. The risk over the timing of depositors' consumption preference motivates their demand for liquidity, and banks provide the freedom of cashing in at optional times by insuring them against their idiosyncratic risk and supporting a Pareto optimal equilibrium.

To achieve this, banks essentially become maturity transformers that take liquid deposits and invest part of the proceeds in illiquid assets. "Banks are able to transform illiquid assets, by offering liabilities with a different, smoother pattern of returns over time than the illiquid assets offer".[3] In doing so they pool risk and enhance welfare, but also create the possibility of self-fulfilling bank runs, a second equilibrium of the game, which is inefficient. Under the 'bad' equilibrium, short-term creditors suddenly withdraw their loans from a solvent borrower. This occurs because it becomes rational for each consumer to pull his money out, if he expects that the other investors will behave in the same way. Because of the illiquidity of the investment, the bank cannot honour all its liabilities if all agents present them for redemption. If everyone decides to run we get a self-fulfilling panic.

The nature of the model suggests that bank panics can be seen as random events, the result of multiple equilibria. The cause of the run can be anything, "a random earnings report, a commonly observed run at some other bank, a negative government forecast, or even sunspots"[4], hence the term 'sunspot' panics.

An important drawback of the Diamond and Dybvig framework was that the liquid investment technology (storage) was completely dominated by the long-term illiquid one. This was the result of their assumption that early liquidation of the long-term productive technology resulted to a payoff equal to the initial investment in this technology, thus matching the service that storage provided. Cooper and Ross (1991) illustrate this characteristic and modify the model to study the importance of salvage value more carefully. They find that, in general, runs will occur for sufficiently large liquidation costs and when consumers are sufficiently risk averse.

Another interesting problem of the Diamond and Dybvig model is highlighted in Postlewaite and Vives (1987). They argue that, strictly speaking, run equilibria in Diamond and Dybvig are

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[3] Diamond and Dybvig (1983), p. 403.

[4] Diamond and Dybvig (1983), p. 410.

not equilibria at all, because consumers would not deposit their funds at the bank in the first place had they anticipated a run. Diamond and Dybvig overcome this problem by linking the equilibrium with some extrinsic random variable (sunspots), which correlates the beliefs of depositors. Then, as long as the probability of the run is sufficiently small, depositors will accept the contract offered by the bank. Alternatively, Postlewaite and Vives present a framework based on the Prisoner's Dilemma situation, in which there is a unique equilibrium involving a positive probability of a bank run. This equilibrium has the feature that it does not have to be conditioned on an exogenous event, such as sunspots.

Alternatively, Cooper and Ross assume that bank runs occur with positive probability and analyse how the knowledge of the possibility of ex-post banking failures affects the design of optimal deposit contracts. They achieve this by considering the ex-ante optimal amongst two contracts, attaching an exogenous probability to liquidation, which acts as a proxy for panics. Our view is that, by doing so, the term panics may not be appropriate any more, and the banking failures are the result of runs, following the signal given by the exogenous event. The choice of contracts is between one that allows for runs and a run-proof alternative. They show that if the probability of a run is high, the banks will choose contracts that eliminate the possibility of bank runs. If the probability of premature liquidation is low, the run-exposed contract is optimal.

An important extension of the Diamond and Dybvig model is provided by Hellwig (1994). Hellwig points out that if the returns of long-term investments are given and the market rate of interest turns out to be high, it is possible that refinancing costs may exceed investment returns. He goes on to recognize that interest rate risk is not diversifiable, since it affects the economy as a whole, and that we should be concerned with its efficient allocation. He builds on Diamond and Dybvig to show that a transfer of risk to depositors is desirable and should accompany the insurance of the depositor's liquidity needs, an action that is not observed in the real world, where financial intermediaries bear a lot of interest rate risk.

2.1.2 Suspension of Convertibility

Diamond and Dybvig identified suspension of convertibility as a mechanism that can eliminate the Pareto-inferior equilibrium of the bank's demand deposit contract. Under a pre-announced policy of suspension of deposit convertibility, the government is obliged to suspend payments and prevent the premature liquidation of the long-term technology, following the observation of depositors panicking and withdrawing from their banks. By doing so, the rationale behind panics is removed, since the depositor's allocations derived from the long-term technology are under no threat. If there are no credibility issues regarding the implementation of suspension of convertibility, the need to put the policy in use will never arise and the Pareto dominated equilibrium is eliminated.

Note that this assumes that aggregate consumption demand is certain. If withdrawals are stochastic however (discussed in the following Section), suspension of convertibility may avert a bank panic but at the cost of optimal risk sharing, since some of the depositors will not be allowed to consume at their preferred time period.

Engineer (1989) shows that in a four-period version of the Diamond and Dybvig model, the policy of suspending deposit convertibility is not as effective. In their paper, suspension ensures solvency of the bank, but does not eliminate the bank run equilibrium. Suppose that all consumers learn their type just before consumption. If a panic does take place, period-one consumers join the queue in the second period, resulting in an excess demand for withdrawal for that period. Non-first-period consumers may fear that they will turn out to be period-two consumers and that, given certain conditions, they may remain cashless, in which case it is optimal to withdraw in the first-period. Bank run conjectures are self-fulfilling and runs may even be possible in cases where the bank can adjust, by using liquidation, to new withdrawal payments after observing a high number of withdrawals.

Gorton (1985) turns to information-based bank runs[5] and in an environment of incomplete information about the bank's investments, portrays a bank's suspension of convertibility as a signal to depositors that continuation of the long-term investments is mutually beneficial. With perfect information, bank runs would be optimal, since depositors would be trying to improve their portfolio positions. If depositors receive a noisy signal about their bank's portfolio returns, they may panic and cause unjustified bank failures. In that case, banks may signal depositors of the state of their investments by suspending convertibility, and not allowing premature liquidation when it is not beneficial to do so.

Gorton's model can be contrasted with Calomiris and Kahn (1991) analysis that portrays demand deposits as a mechanism to provide incentive-compatible intermediation. In their view, liquidation of banks following bad signals concerning their portfolios is designed to place the portfolio's assets beyond the reach of the banker. This justifies the decision to take the suspension decision away from individual banks, since suspension of convertibility would destroy the demandable-debt property of bank deposits.

Selgin (1993) shows that bank suspension contracts may be a low cost alternative to deposit insurance given the absence of regulatory interference. He points out that the Diamond and Dybvig framework does not allow for bank checks or notes. He incorporates this possibility and assumes that following suspension, banks restrict payments on high-powered money, but continue to receive and issue bank debt, which is a close substitute to outside money. By doing so, he shows that suspending convertibility does not have to be associated with considerable welfare losses on the side of depositors due to consumption restrictions on outside money. In the absence of legislative interference (restricting bank debt issuance or imposing bank holidays with suspension of all bank activities) Selgin concludes that suspending convertibility may be a desirable alternative to deposit insurance.

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[5] See Section 2.1.4.

2.1.3 Sequential Service Constraint and Aggregate Uncertainty over Consumption Demand

An important ingredient of the Diamond and Dybvig framework is the existence of a sequential service constraint. Given the first-come first-served rule and the illiquidity of the bank's long-term assets, if a panic was to take place the agents at the end of the line would suffer losses, receiving less than what was promised. In order to avoid incurring such losses, they will choose to step to the head of the line, causing the very event they imagined.

Three issues arise regarding the sequential service constraint. Firstly, without the sequential service constraint, panics would not take place. The first-come first-served rule ensures that contracts with consumption payments contingent on the total number of agents in line are inconsistent. By preventing the allocation of the bank's resources on a pro rata basis, the possibility of bank panics remains present.

As a consequence, a second issue is raised, since the absence of such an arrangement would result in a framework that would not reflect the history of banking. Banking panics are historically recurring phenomena and models of banks should account for these events.

Finally, the omission of the constraint would lead to the establishment of an efficient early credit market, inconsistent with voluntary participation in an illiquid banking arrangement. Jacklin (1987) emphasises this point. Note that a demand deposit economy provides better risk sharing than the market economy, but is vulnerable to bank runs. Jacklin asks the question of whether alternative arrangements could improve or match the risk sharing property of the demand deposit contract, while at the same time avoiding the risk element of bank panics associated with it. Jacklin demonstrates that dividend paying equity shares will dominate the demand deposit contract in the Diamond and Dybvig environment, unless the markets are incomplete in some important way, thus opening the model to the Fama (1980) critique, which questions the special role for banks in the economy.

This has led to a number of explanations for the demandable debt finance of banks. In Jacklin demand deposits facilitate risk sharing utilizing trading restrictions included in the contract. Villamil (1991) combines features of the Diamond and Dybvig and the Townsend (1979) models and uses costly state verification to resolve the demand deposit/demand equity indeterminacy problem and rationalize debt contracts. Calomiris and Kahn (1991) show that demandable debt acts as a disciplining tool against moral hazard by bank managers. Some depositors engage in costly monitoring of bank behaviour and withdraw their funds if they detect fraud or unacceptable high asset risk. The sequential service constraint is essential in their model to avoid a free-rider effect from depositors that do not incur the monitoring costs. Jacklin and Bhattacharya (1988), in an environment with risky long-term assets and interim information regarding their productivity, show that the choice between deposit contracts and traded equity contracts depends crucially on the risk of and information about available investments.

Wallace (1988) addressed these issues by introducing a restriction as part of the economic environment. He provided a justification for the sequential service constraint by suggesting the spatial separation of agents. If consumers are assumed to be isolated, then they will be prevented from co-ordinating their withdrawal. Panics are still possible and there is no conflict with historical facts. Furthermore, banking can be seen as a substitute for market activity in a world where agents are isolated. In essence, Wallace's isolation imposes exogenous market incompleteness to the model.

By investigating the nature and importance of the sequential service constraint, Wallace's paper tries to resolve another problem of the original Diamond and Dybvig model.

Diamond and Dybvig proposed suspension of convertibility as a mechanism that eliminates the Pareto dominated equilibrium in their framework.[6] Nevertheless this policy is inefficient in the presence of aggregate uncertainty over consumption preference. Diamond and Dybvig argue that the alternative policy of government deposit insurance can achieve optimal risk sharing as a unique Nash equilibrium. Deposit insurance is portrayed as a redistributing tax, conditional on the proportion of early withdrawals, applied to early withdrawers and guaranteeing all promised allocations. Such a policy eliminates the incentive of late consumers to withdraw early and thus makes the use of the policy costless, since the credible promise of implementation ensures that the need for the policy will never arise.

Wallace (1988, 1990) identifies a flow in the design of deposit insurance. If the sequential service constraint, assumed throughout the Diamond and Dybvig model, is to be taken seriously the option of observing the total number of early withdrawers and subsequently deciding on the allocation to be distributed is not permitted. Even if the government can apply such a redistributing tax after the observation of all early withdrawals, there is no guarantee that agents will not have already consumed their withdrawals. Instead, Wallace suggests an alternative policy that imitates partial suspension of convertibility. He demonstrates that the best attainable solution

[6] We discuss this policy in Section 2.1.2.

to the aggregate uncertainty problem, although not first best, must form a contingency in the order of withdrawal.

His solution however excludes the possibility of the formation of an interbank market. Bhattacharya and Gale (1987) reinterpret aggregate uncertainty as a problem faced among spatially separated intermediaries subject to privately observed shocks regarding early withdrawal demand. Given imperfect correlation, borrowing and lending among banks can be seen as insurance against these shocks. An important element in the formation of the interbank contract is the inclusion of incentive compatibility constraints to avoid the inherent moral hazard arising from the assumption that the liquidity shocks are unobservable. These second-best distortions prevent the inter-bank arrangement from achieving optimality.[7]

Nevertheless, Bhattacharya and Gale's solution has a similar flaw to that of the deposit insurance policy of the Diamond and Dybvig model. The design of the contracts between depositors and banks, given participation in an inter-bank arrangement, does not respect the sequential service constraint. This is because the contracts specify early consumption

[7] Another interesting view on the purpose of interbank markets is given in Bhattacharya and Fulghieri (1994). They analyse a model of interbank coordination where banks face maturity uncertainty of their short-term investments. Similarly to Bhattacharya and Gale, information asymmetries result in a second-best interbank contract.

allocations contingent on the number of withdrawals. As a consequence, banks will be unable to provide the correct allocation corresponding to their true liquidity pattern to the first depositor in line, since they only learn their type by an observation made further down the queue. The first-come first-serve assumption implies that all banks must make one common early consumption allocation promise.

2.1.4 Information-Based Bank Runs

The main question regarding the model of Diamond and Dybvig arises in relation to the causes of panics. In other words, the sunspot-based model seems to lack a trigger mechanism for the panics, as we have already discussed.

Adding to the research already questioning the existence of a run equilibrium in the Diamond and Dybvig model, a paper by Green and Leen (2000) suggests that we must consider alternative venues for explaining the observed bank failures of the real world. Green and Leen demonstrate, in an environment without and with a sequential service constraint and where the size of the population is observable by individual agents, that agents' dominant strategy is to tell the truth regarding their unobservable consumption preference, thus eliminating the banking panic equilibrium. Note however, as they point out themselves, that their results would not hold in overlapping generations models, or if the size of the queue or the agent's order in the queue for withdrawals is not observable.

An alternative view on the cause of bank failures offers a more clear rationale for their existence. This view tries to model runs triggered by fundamentals, in contrast to pure panics as suggested by the sunspot theory developed by Diamond and Dybvig. In Jacklin and Bhattacharya (1988), the long-term investment is risky, in the sense that it offers a variable return. Runs are the consequence of rational revisions in beliefs about the riskiness of the bank's portfolio performance. Depositors preference for early withdrawal cannot be supported by the bank's assets, leading to 'information-based' bank runs. Note that when a run takes place it is the only equilibrium.

A number of further differences with the Diamond and Dybvig model are also worth mentioning. Jacklin and Bhattacharya, following Jacklin (1987), make use of smooth preferences (utility over two time periods) unlike Diamond and Dybvig, who assume that agents have realized utility for either the first or the second period of the game (corner preferences). Furthermore, Jacklin and Bhattacharya assume additive square root utility for consumption, implying a relative risk aversion of less than one, and a totally illiquid long-lived asset. Diamond and

Dybvig, on the other hand, assume a relative risk aversion of more than one and total recovery of the investment if premature liquidation of the productive technology takes place.

An important study of the Jacklin and Bhattacharya framework is that of Alonso (1996). Alonso considers alternative contracts that can possibly eliminate information-based runs. He notes that a contract could be written that makes allocations contingent on the interim signal received regarding the bank's portfolio returns. Just like Jacklin and Bhattacharya he chooses to abstract from such a possibility by constraining the possible design of contracts and asserts that ideally such a restriction should be justified by the explicit environment. Instead, Alonso concentrates on a contract that includes an incentive compatibility constraint that prevents information runs even in the worst possible state of fundamentals. He compares the ex-ante optimality of such a contract with a contract subject to runs to find that excluding the possibility of bank runs may not always be the optimal bank behaviour ex-ante. More specifically, if a low probability is attached to the bad state of the bank's portfolio returns, the total utility of a contract with runs is only slightly affected and a run-proof contract, that alters all allocations considerably, might not be ex-ante desirable by the banks.

Chari and Jagannathan (1988) emphasize the panic aspect of information-based runs. A portion of the depositors obtains interim information about the true values of their bank's assets, while another portion does not receive the signal. Depositors of the latter portion can only learn about the state of the bank by observing the line of depositors withdrawing their funds. However they cannot distinguish whether there is a long line because of consumption needs or because informed depositors are getting out early. Panic is the result of their inference, which may be correct or not, that the bank is about to fail. This panic view is based on asymmetric information and a signal extraction problem, as the information is imperfectly revealed to depositors by the withdrawal decision of other depositors. However, an important drawback of their model is that the authors have abstracted from the important issue of the services that banks provide, by making all investors risk neutral, with the consequence that deposits are not needed to provide insurance. Note that suspension of convertibility is crucial for the existence of their bank contract, which yields superior allocations to the market equilibrium in terms of ex-ante expected utility, leaving however some individuals worse off ex-post than others.

A different kind of panic-based bank runs is studied by Goldstein and Pauzner (2000).[8] Goldstein and Pauzner use the

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[8] A simpler version of their environment is studied by Morris and Shin (2000), whose purpose is to bring out the importance of this type of methodological analysis

same technique as the study on currency crises by Morris and Shin (1998a,b) to derive a unique equilibrium in contrast to the multiple equilibria of Diamond and Dybvig. Agents receive an interim noisy signal regarding the state of their bank's investments. The small error term in their information, in combination with the uncertainty surrounding other agents' actions, results in a unique threshold such that each agent that receives a signal below this will run to the bank. Note the panic element of this framework: runs occur even when the fundamentals are not sufficiently low to encourage an agent to run had he believed that others do not run.

Another model that adapts the information-based view of bank failures is that of Allen and Gale (1998), who develop a framework in which bank runs take place when depositors learn that their bank's portfolio is performing badly. Allen and Gale demonstrate that bank runs can be first best efficient, as they allow efficient risk sharing between depositors. However, this result does not stand if liquidation costs are considered, which is studied by assuming that the return to storage by early withdrawing late consumers is lower than the return obtained by the bank. In that case they find that central bank intervention will be necessary to improve welfare. Furthermore, Samartin (2000) alters the model of Allen and Gale by introducing smoother preferences, following Jacklin (1987). The result is that a laissezfaire response by the government is never optimal and that regulation is necessary and welfare improving. Samartin essentially restores the traditional view that bank runs are costly and should be prevented. Finally note that, as Allen and Gale also point out, their framework discards the assumption of first-come first-served.[9]

More support for the information-based run view can be found in Agenor and Aizenman (2000). Agenor and Aizenman embed an information-based runs story in a costly state verification environment (developed by Townsend (1979)). They show that in the presence of financial sector inefficiencies, like verification and enforcement needs, bank runs are more vulnerable to economic fundamentals. Furthermore, they find that, given risk averse agents and risk neutral banks, deposit contracts can only provide partial insurance against macroeconomic shocks.

[9] We discuss the sequential service constraint in Section 2.1.3.

2.1.5 Contagion

Models of contagion in the banking sector, building on the framework of the Diamond and Dybvig model, have given weight to the role of the interbank system, following the work of Bhattacharya and Gale (1987), as a form of propagation of bank failures. General introductions to the issue of contagious bank failures can be found in Temzelides (1997) and De Bandt and Hartmann (2000). We first review inter-bank based contagion, before having a look at two noticeable exceptions.

Rochet and Tirole (1996) analyse interbank lending in the presence of moral hazard and peer monitoring among banks. They show how an interbank market solves the moral hazard problem between bank owners and bank-debt holders, but introduces contagion risk. Their model suggests that government intervention destroys peer monitoring among banks, given that banks' information about each other can be used efficiently.

Freixas, Parigi and Rochet (2000) make use of the Diamond and Dybvig framework to produce a model where financial connections among regions arise because depositors face uncertainty about the location they want to consume. Depositors that have to consume in a different location than the one where they deposited their money, will ask for withdrawal and transference of their allocations to their geographical consumption area. Banks will create credit lines among them, in order to service these orders and to avoid liquidation of long-term investments. However, two equilibria arise in this case, even if all participating intermediaries are solvent. The credit-line equilibrium involves an efficient interbank arrangement, while the gridlock equilibrium results in contagious bank failures, the result of panic among depositors from fear of insufficient reserves and premature liquidation of investments. The case of an insolvent participant in the interbank arrangement is also discussed, taking into account a number of possibilities for the existence and direction of credit lines among banks.

The role of geography and the pattern of linkages among banks in an inter-bank model are also explored in Allen and Gale (2000). In their model, the need for an interbank market emerges because of imperfectly correlated liquidity shocks across regions. In the case of higher than expected withdrawals in one of the regions participating in the interbank mechanism (a world state whose realization was assigned a zero probability in the planning period), financial contagion is inevitable. Allen and Gale study how the structure of claims will affect the spread of the contagion, and conclude that more complete (inter-linked) markets are likely to be more stable.

Aghion, Bolton and Dewatripont (2000) also focus on the contagious risk that is associated with the insurance of banks against liquidity shocks, but do so using incomplete information. They reject a fully contingent interbank market, where banks offer loans according to global liquidity supply, as unrealistic and instead focus on a clearing house that offers a fixed inter-bank lending rate. If one bank becomes illiquid and is not supported by the inter-bank market, a contagious bank panic may spread to an otherwise solvent system, because depositors may incorrectly infer that the inter-bank arrangement lacks sufficient liquidity.

An interesting advance on the work of Bhattacharya and Gale on interbank co-ordination is provided by Koppl and MacGee (2001). They add asset risk in the analysis of the formation of borrowing and lending arrangements among banks and investigate its interaction with liquidity risk. The possibility of bank failures arises from bad performing assets and information received about them from depositors, unlike previous inter-bank research that focuses on uncertainty over liquidity demand. Note that in their model, asset shocks to a few banks do not lead to system wide crisis, which can stem only from general banking sector bad performance.

Theoretical papers that break away from the traditional inter-bank propagation mechanism are those of Bougheas (1999) and Chen (1999).

Bougheas presents an overlapping generations model based on the information-based bank run view of Jacklin and Bhattacharya. In his model, banks hold positively correlated portfolios, which act as an updating mechanism among depositors of different banks. Bougheas shows that the insolvency of one bank in the system is not by itself a sufficient condition for the panic to spread the crisis to the rest of the economy. Instead, bank failures become contagious only when the depressed state of the economy signals that the asset returns across the banking system are positively correlated.

Alternatively, Chen concentrates on the importance of the number of failed banks acting as a signal about the prospects of the banking industry. Chen assumes that depositors in some banks in the economy receive bank specific information about the health of their bank's portfolios. Following this interim information a number of bank failures might take place, which are observed by the depositors of banks for which no information is available. A panic might arise if the number of failures suggests that the macroeconomic conditions have worsened and banks' portfolios are under performing. Note that Chen terms as panic the decision made from depositors to react to early information (the number of failed banks) and not wait for more bank specific information. He then goes on to identify deposit insurance as a mechanism that would eliminate panic and induce depositors to wait until bank specific information is available.

2.1.6 Empirical Research on Banking Crises

Empirical research has tried to address the nature of banking failures, given the existence of two competing theories: sunspot panics and information-based bank runs. The latter view has received the most support.

Gorton (1988) examines seven panics during the US National Banking Era (1863-1914) and makes the case that these were not random events, as the sunspot theory would suggest, but instead can be explained by depositor responses to changing perceptions of risk due to cyclical downturns. He then argues that noisy information predicting recessions is the most fitting explanation of banking crises. This conclusion is further supported by Calomiris and Gorton (1991).

Aharony and Swary (1983) study the three largest US bank failures since 1978, Swary (1986) studies the 1984 crisis of Continental Illinois and Karafiath and Glascock (1989) study the effects of the 1982 Penn Square Bank failure. They support the information-based view as an explanation of bank runs and contagion in the banking sector.

An interesting study by Aharony and Swary (1996) concentrates on five large-bank failures in the Southwest region of the US during the mid-1980's. They use observable proxies to find whether depositors used interim private information for their assessment of the riskiness of their bank's long-lived assets and their findings are also consistent with an information-based contagion hypothesis.

Furthermore, Park (1991) shows that bank failures are contagious due to the lack of bank-specific information. Calomiris and Mason (1997) deal with the 1932 Chicago bank panic during the great depression and also find that asymmetric information between depositors and banks can precipitate banking failures. Saunders and Wilson (1996) study deposit flows of 163 failed and 229 surviving banks in the US from 1929 to 1993 and find support for the view that a number of informed depositors distinguish among ex ante failing and non-failing banks. Schumacher (2000) turns to the Argentinean banking panic of 1994, supporting the information-based theory approach and noting how suspensions of troubled banks have spillover effects on banks of similar characteristics.

Thus, the empirical evidence largely suggests that an information-based approach seems more suitable for the study of banking failures and contagious panics in the banking sector. Note also the link between banking and currency crises, which we further explored in the following Sections. Demirgüç-Kunt and Detragiache (1998) study a sample of 45 to 60 developing and industrial countries between 1980 and 1994. Their results are consistent with the information-based view and among their findings they note that vulnerability to balance of payments crises contributes to the likelihood of banking sector problems.

2.2 Financial Crises: Overview

A currency crisis can be defined as a sharp decline in the nominal value of a currency or a sharp depreciation.[10] A large amount of research has focused on the reasons behind such crises. At the theoretical level we can distinguish between three types of models.

The first type, following Krugman (1979), identifies weaknesses in economic fundamentals as the cause of currency crises, making the maintenance of pegged exchange rate systems unsustainable and the subsequent crisis inevitable. This type of models was mainly developed over the 1980s to explain crises in Latin American countries. Following the speculative attacks on countries participating in the Exchange Rate Mechanism of the European Monetary System in 1992-93, that took place despite sound fundamentals not justifying speculation, a second type of models emerged.

The second type of models, based on Obstfeld (1986), focused on multiple equilibria and the self-fulfilling nature of

[10] This is a strict criterion that would not allow for cases where the currency came under severe pressure but the authorities successfully defended it. To capture these instances, we could add in the definition the cases where authorities are forced to intervene heavily in the foreign exchange market or raise interest rates sharply to absorb pressure.

currency crises. They noted that the willingness of the government to maintain an exchange rate peg is inversely related to the number of speculators attacking the currency. Consequently, the individual speculator faces increasing incentives to attack the currency as more speculators do so, and an attack may be launched, even if the fundamentals are not in a very bad state. An important contribution of these models was that they highlighted the difficulty in predicting speculative attacks. One of their weaknesses, namely that they rely on sudden changes in mood caused by unrelated events (sunspots) and resulting to jumps from one equilibrium to another, has been the subject of study by Morris and Shin (1998a,b). The indeterminacy of equilibria is removed by adding a small uncertainty in information about fundamentals, resulting in a unique equilibrium.

Since the East Asian Crisis of 1997 and the empirical evidence provided by Kaminsky and Reinhart (1999) on the correlation between currency and banking crises, a growing literature has concentrated on twin crises.

The literature on currency and on banking crises developed independently, nevertheless along similar lines as Marion (1999) observes. The two types of crises exhibit similar characteristics. Both types of attacks are against a price-fixing policy, whether this refers to a fixed price for foreign currency or a fixed price between deposits and currency. The exhaustion of reserves, be it foreign currency reserves or the bank's liquid assets, leads to the abandonment of the regime. Furthermore, both types of crises are the result of either multiple equilibria (sudden shifts in market expectations) or policy inconsistencies (trying to maintain the price fix despite bad fundamentals).

We review the theoretical and empirical work that has been carried out on twin crises, and make the observation that models linking the two sectors of the economy have done so choosing only one of the possible ways to relate the crises. More specifically the standard approach utilises the existence of foreign capital in the domestic banking system, leaving other possibilities unexplored, for example the role of domestic depositors.

2.2.1 Non-Financial Models of Currency Crises: First and Second Generation

A convenient way of characterising currency crises models that do not involve the banking sector has been the distinction between first and second generation models, introduced by Eichengreen et al (1995).

First generation models, otherwise known as the standard or the traditional approach to currency crises, follow Krugman (1979), who extended the work of Salant and Henderson (1978) on schemes to stabilize commodity prices. These models direct attention to government policy inconsistencies between a fixed exchange rate commitment and the pursuit of domestic policies, such as monetising large fiscal and current account deficits. More specifically, they emphasize speculative attacks as runs on the foreign exchange reserves of the central bank. Macroeconomic policies inconsistent with the sustainability of the peg lead to a speculative attack in which rational market participants buy the foreign exchange reserves of the central bank, leading to the collapse of the currency regime.

An important contribution of these models was to explain the currency attacks as rational and not the result of panic actions from the speculators. Furthermore they fitted the economic phenomena of the time, with stabilisation plans during the 1970s and 1980s widely failing in Latin American countries, due to the monetary and fiscal policies followed by those countries' governments and not because of some malfunction of foreign exchange markets. Note that the crises, though sudden, are deterministic events. They are unavoidable, given the policies followed, and in principle their timing is predictable.

As noted, first generation models point to unfavourable developments in some of the fundamental macroeconomic variables as the main cause of speculations and pressures on the currency. The limitations of this type of models became obvious with the 1992/93 exit of the United Kingdom from the Exchange Rate Mechanism, since there were no expansionary macroeconomic policies justifying the speculative attacks.

Second generation models were developed, based on Obstfeld (1986). These models view currency crises as shifts between different monetary policy equilibria in response to self-fulfilling speculative attacks. Instead of focusing on government economic policies, the emphasis is on market expectations, multiple equilibria and herding behaviour of investors. Market speculators base their beliefs on the willingness of the government to resist pressure on the fixed exchange rate regime. When they perceive that conditions, such as high unemployment, compromise the government's willingness to defend the peg, speculators initiate their attacks.

Second generation models differ from first generation models in that they offer no predictability of the crises. It has also been argued that they don't involve irresponsible government policies (other than insufficient commitment to the exchange rate peg) and thus they take the blame off the policy makers' shoulders. However, as Jeanne (1997) demonstrates, multiple equilibria are only possible for only a specific range of fundamentals. Thus policy makers' responsibility is restored, since governments should try to avoid this range, for example by reducing exposure to short maturity of foreign debt.

This type of models faced criticism because of the nature of multiple equilibria. The jump from the good to the bad equilibrium, where a currency run takes place, cannot be justified. Critical questions, like why did the attacks take place when they did or what policies should be followed to avoid them, are left unanswered. Morris and Shin (1998a,b) provide a solution, where incomplete information, portrayed as noisy signals about fundamentals and uncertainty over other agents' reactions result in a unique equilibrium. Specifically, they demonstrate that a switching point exists in fundamentals, below which an attack is certain and above which no attack takes place.

Morris and Shin demonstrate this for a uniform or normal distribution of fundamentals, and Heinemann and Illing (2000) extend their work to a broader class of probability distributions.

2.2.2 Third Generation Models and Jeanne's Objection

The 1997-98 East Asian crisis was quickly termed by economists as a new era of exchange rate crises. Perhaps the most disturbing aspect of the crisis was the fact that traditional crisis models did not predict it. Indeed inflation and unemployment did not constitute a problem, government deficits were low, capital inflows continued and interestingly credit ratings from all agencies were high. Most importantly financial intermediaries seemed to have been central players. Having to explain the new phenomena, a third generation of models had to be created or if not so, a reliable extension of the existing model types to be built in order to accommodate the characteristics of the East Asian crises.

In the following Section we concentrate on models combining banking failures, as described by Diamond and Dybvig, with currency crises, following mainly the methodology of second generation self-fulfilling attacks. Other strands followed by the literature can be found in Radelet and Sachs (1998).

We must point out that objections have been raised with regard to the decision to apply the term of third generation models to this type of models. Jeanne (1999) points out that in second generation models the abandonment of the peg is the consequence of the incentives that the policymaker is faced with, when considering whether or not to devalue. Under this view, any variables entering the objective function of the policy maker can qualify as economic fundamentals influencing the speculators' decision over the government's reaction to a speculative attack. Thus, models stressing the significance of the health of the banking sector, which are explored in the following Section, can only qualify as extensions or sub-cases of the older types of currency crises models.

2.2.3 Twin Crises Models

The literature that extends the Diamond and Dybvig model to an open economy framework has concentrated in the importance of flows of capital in the banking sector originating from foreign investors or lenders. There have been two ways of introducing this foreign intervention in the domestic economy. One way is to assume that foreign investors have to use domestic intermediaries to participate in domestic technologies. The other assumes that the domestic banking sector can borrow from the international community and has to repay in some future date. We first consider research that concentrates on these sources of foreign capital inflows and financial instability, before we examine another type of twin crises models that emphasises the cross-border contagion aspect of financial crises.

Perhaps the technique of combining banking with currency crises that has received the most attention is that of Chang and Velasco (1998a). In this type of papers, foreign borrowing from abroad is introduced, altering the budget constraints of the domestic banks. In the framework of Chang and Velasco, a shift to pessimistic expectations by foreign creditors induces them to stop lending and prevents them from rolling over the domestic banks' short-term debt. The liquidity of the banks is reduced and their vulnerability to a panic is increased.

Foreign borrowing has been used by Chang and Velasco to study alternative exchange rate regimes and government policies in the case of twin crises, the international illiquidity of domestic financial systems and the importance of the maturity of external debt of banks.

Chang and Velasco (1998a) embed the maturity transformation story of the banking sector in a general equilibrium macroeconomic model, which can operate under a number of regimes. The combination of flexible exchange rates and a lender of last resort is found to dominate all other policy regimes in their framework. In the last Section of their first paper they also discuss the availability of international capital, a subject which becomes more central in their second paper.

In Chang and Velasco (1998b) illiquidity is defined as a situation in which the financial system's potential short-term obligations exceed the liquidation value of its assets. They argue that the illiquidity problem can be aggravated by financial liberalization and point out that domestic banks become particularly vulnerable if their foreign loans are of short maturity. The financial system can greatly magnify the effects of small external changes, like world interest rates or competitiveness, resulting in costly financial distress. Moral hazard is also considered as a factor increasing the fragility of the banks.

A third study by Chang and Velasco (2000) follows Cooper and Ross, and allow for banks to take the possibility of self-fulfilling runs into account in the design of their contracts and portfolio.[11] For low probabilities of runs, the intermediaries choose contracts that are subject to illiquidity and bank runs. By allowing for short and long term loans, Chang and Velasco show that the term structure of interest rates emerges endogenously and that short term debt is less expensive than long term debt. The

[11] Chang and Velasco alter the usual assumption of the banking literature that the probability of runs is effectively zero. For more on this

intuition behind this result is that following a crisis long term debt can be completely defaulted, unlike short term debt that will be partially honoured. They also observe that the maturity structure of foreign debt will depend on attitudes towards risk. Two effects come into play in reaching this result. Short term debt may be cheaper than long-term, but in the case of a banking panic depositors total welfare decreases because international short-term creditors also panic and liquidate their investments. Chang and Velasco find that high risk aversion implies portfolios with at least some short-term debt.

The link to an exchange rate collapse in the framework of Chang and Velasco is the recognition of two mutually incompatible objectives, the stabilization of the banking system and the preservation of the exchange rate peg. A Central Bank may try to keep interest rates from rising or provide lender of last resort funds in order to fight a bank crisis, but then the agents may use the additional domestic currency to buy reserves. With the depletion of the foreign exchange reserves, the currency regime collapses and we have twin crises. Note that these studies concentrate on sunspot panics and do not allow for risky investments.

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assumption see Section 2.1.1, Postlewaite and Vives (1987), Cooper and Ross (1991) and Alonso (1996).

Takeda (2001) alters the Chang and Velasco model where domestic banks borrow from abroad, by allowing for the return of the long-term technology to depend on the random state of the world. However, note that Takeda does not consider the possibility of information based bank runs in the sense of Jacklin and Bhattacharya. More specifically he makes use of Goldstein and Pauzner (2000) techniques by introducing noisy signals, regarding interim information on fundamentals, in order to derive a unique equilibrium in which economic fundamentals determine whether a currency and financial crisis will occur. Bad signals force depositors to coordinate their actions and cause a run, while good signals have no repercussions. The main finding of their study is that capital inflows may increase the probability of crises when the return on domestic investment is lower than international interest rates.

Allen and Gale (2000) also extend their previous paper on optimal banking crises, which also features a risky asset, to an international context to study optimal currency crises.[12] Following Chang and Velasco's research, they open up their economy by introducing an international bond market, where the domestic country can borrow from foreign lenders. International bonds replace the storage technology and liquidity is obtained for

[12] Comments on their basic set-up, Allen and Gale (1998), can be found in Section 2.1.4.

early consumers by borrowing from foreign lenders. Allen and Gale then examine different set-ups, regarding bank debt and central bank monetary policy, and their consequences, regarding optimal risk sharing among depositors and the transfer of the long-term asset's risk to the risk neutral international bond market. They make recommendations with respect to advanced industrial economies and emerging markets (the main difference being that industrial countries can issue debt in their own domestic currency, unlike developing countries) and study the role of an international organization like the International Monetary Fund or the influence of U.S. Federal Reserve in financial crises. They conclude that large exchange rate movements are desirable, in the sense that they allow risk sharing with the international market, and that in some, but not all, cases an international lender of last resort can prevent costly liquidations and financial contagion.

An alternative view on combining the banking and currency sectors of the economy in producing financial crises, is also based on foreign capital inflows. It stresses the importance of foreign investors participating in domestic investments through domestic financial intermediaries.

Unlike Chang and Velasco, Goldfajn and Valdés (1997) highlight the interactions between capital flows and the twin crises, by pointing out that intermediaries, allowing more flexibility and offering more liquid assets, improve the attractiveness of the economy in the eyes of foreign investors. Intermediation has two main effects. On one hand it can increase the capital inflows in the economy, while on the other hand it may generate runs, amplifying initial shocks that otherwise would not have generated crises. In this situation, the function of intermediation produces strong capital movements and exchange rate overreaction. Furthermore, the expectation of an exchange rate collapse exacerbates the financial fragility of the intermediaries by reducing the return of their investments in the event of runs.

Foreign investors participating in domestic technologies through domestic financial institutions are also the link to international markets in the work of Diamond and Rajan (2000). The authors observe that short-term foreign debt has been associated with high financial fragility and ask which way causation actually runs. Unlike the traditional view, that blames short-term debt for causing crises, they believe that short-term debt is the consequence of illiquid or unhealthy financial systems and not the direct cause of crises. More specifically, they show that liquidity creation or the low quality of domestic investments result in the more frequent use of short-term financing. They warrant against banning short term debt, an action which may enhance the system's stability but could have significant consequences for credit creation. Note that, as the authors point out, their model is not of an open economy with a fixed exchange rate, but can still be used to gain insights for financial crises.

Goldstein (2002) offers an interesting paper on strategic complementarities between groups of depositors in the domestic banking system and speculators in the foreign currency market. Just like in Diamond and Dybvig, the incentive of the individual depositor to withdraw early is higher the more withdrawers do so.[13] Just like in Obstfeld, the incentive of the individual speculator to attack the currency is higher the more speculators do so.[14] The authors go one step further by linking the incentives of bank depositors to withdraw with the incentives of foreign exchange market speculators to attack the currency. They consider foreign agents holding deposits with domestic banks, a domestic asset yielding output in domestic and foreign currency and banks making promised allocations in foreign currency. If speculators are to attack the peg successfully, depreciation will result in fewer resources for the domestic banking system,

[13] In Diamond and Dybvig the source of complementarities is the lack of liquidity in the short term, while in Goldstein complementarities are achieved by assuming that the long term return of the available investment is a decreasing function of early withdrawals, due to increasing returns to scale in aggregate investment.

[14] Because the reserves available for the government to defend the peg decrease, thus raising the cost of defending the currency regime.

making it also optimal for the foreign depositors to run on banks. Furthermore, if foreign depositors are to run on banks, they indirectly reduce the foreign reserves that the government has, and it therefore becomes optimal for speculators to attack the peg. The probability of one type of crisis increases as the probability of the other type increases, and a vicious cycle results in a destabilizing environment with correlation among currency and banking crises.

Note the repetitive remark regarding the twin crisis models that we have reviewed in this Section, that they rely on foreign capital flows to produce the link between the banking and the currency sectors. Either foreign investors or borrowing from abroad have been considered, leaving other venues, like the role of domestic depositors, unexplored.

Furthermore, as Miller (1998b) points out, the foreign capital from abroad can be used to demonstrate cross-border contagion. We could have foreign banking crises generating currency crises domestically. If the foreign banks are important extenders of credit to the domestic country or if foreign investors have invested in the domestic country, a banking crisis abroad could result in the repatriation of capital, causing a currency peg collapse in the domestic country. This reinterpretation modifies the models of twin crises we reviewed so far to international financial contagion mechanisms. Stopping foreign lending or the roll over of the domestic banks' short term debt results in turn in domestic banking sector crisis, and the contagious financial flu can go on spreading across the open economies.

Another interesting cross-border contagion venue is domestic banks lending to domestic companies that are highly exposed abroad or with currency mismatched portfolios, where more assets than liabilities are denominated in terms of the devaluing foreign currency. In this case we would observe a currency crisis abroad resulting in a domestic banking crisis.

Miller (1998a) building on Garber and Grilli (1989) considers one of these cross-border cases.[15] Consider a large home country and a small foreign one, which pegs its currency to the domestic one. When domestic banks invest abroad, a domestic bank run will repatriate foreign capital, which may cause a depletion of the foreign country's reserves and force a devaluation of the foreign currency. Devaluation will then render domestic banks insolvent. While in Garber and Grilli bank solvency problems occur when the forced early liquidation of long-term securities causes a drop in asset values, in Miller's paper solvency problems arise when the forced repatriation of foreign investments causes a devaluation of the foreign currency

[15] Garber and Grilli, in a paper before the East Asian Crisis, studied the possibility of bank runs and contagion in open economies. Nevertheless,

and thus a drop in the domestic currency value of assets denominated in foreign currency. In effect, domestic bank runs cause a speculative attack on the foreign currency and are self-justified.

2.2.4 Empirical Research on Twin Crises

Empirical research has mainly concentrated on either banking crises or currency crises, with only a few exceptions associating the two. In fact, the empirical study of links between banking and currency crises can only be found in Kaminsky and Reinhart (1999) and Glick and Hutchison (1999).[16]

Kaminsky and Reinhart study 20 countries for the period 1970-1995, where the selected countries are small open economies, with a fixed exchange rate, crawling peg or band. Their study encompasses 26 banking crises and 76 currency crises and they find that more than 25 percent of the banking crises happen within one year of the currency crises. Glick and

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they ignored the possibility of currency risk and did not explore the issue of twin crises.

[16] Studies on the importance of financial liberalization for financial crises, not directly related to the phenomena of twin crises but closely associated to the field, include: Demirgüç-Kunt and Detragiache (1998), Rossi (1999) and Gourinchas, Valdés and Landerretche (2000).

Hutchison analyse 90 industrial and developing countries for the period 1975-97, with 90 banking and 202 currency crises episodes, while they identify 37 twin crises.

Kaminsky and Reinhart conclude that a banking crisis helps predict a future currency crisis, the converse not being true. They find that the collapse of the currency deepens a banking crisis, activating a vicious spiral and they point to common causes behind banking and currency crises. They also note that weak and deteriorating fundamentals were typical prior to crises, and significantly worse fundamentals accompanied twin crises in comparison to isolated banking or currency crises. Their study shows no apparent link between currency and banking crises prior to 1980s, and they suggest that the financial liberalization of those years resulted in linkages between the crises.

Glick and Hutchison complement these results by stressing that banking crises are a good leading indicator about the possibility of currency crises, with the link not holding in the opposite direction. They also point out that the twin crises phenomenon is concentrated in financially liberalized emerging market economies.

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CHAPTER 3

Basic Model: Sunspot Panics and Information-Based Bank Runs

3.1 Introduction

Our basic model is a hybrid combining the environment of Diamond and Dybvig (1983) and of Jacklin and Bhattacharya (1988). Diamond and Dybvig, following Bryant (1980), made an important contribution to the theory of banking, by creating a microeconomic model that captures two functions of the banking sector. By specifically addressing the issues of maturity matching between assets and liabilities, and the provision of insurance to depositors against liquidity risks, they show that bank deposit contracts can be optimal and yet lead to banking sector panics.

Bank panics, according to Diamond and Dybvig, can be seen as random events, the result of multiple equilibria. The cause of a run can be anything, "a random earnings report, a commonly observed run at some other bank, a negative government forecast, or even sunspots" (p. 410), hence the term 'sunspot' panics.[1] Alternatively, information-based bank runs, such as in Jacklin and Bhattacharya, offer a more clear rationale. Runs are caused by rational revisions in beliefs about the riskiness of the bank's portfolio performance.[2] While in Diamond and Dybvig bank runs occur because depositors collectively choose a Pareto-dominated equilibrium, in Jacklin and Bhattacharya interim information about the bank's investment in the risky long-lived assets causes depositors to prefer early withdrawal, a demand that the bank cannot support with its assets, leading to 'information-based' bank runs.[3]

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[1] In Diamond and Dybvig banks are vulnerable to runs because of the existence of multiple equilibria. Postlewaite and Vives (1987) present an example based on Prisoner's Dilemma, where a bank run can exist as a unique equilibrium with positive probability. This equilibrium has the feature that it does not have to be conditioned on an exogenous event, such as sunspots.

[2] Alonso (1996) makes the banks fully rational, in the sense of allowing them to design their contracts with the knowledge that bank runs can take place. In this environment, banks can design run-preventing deposit contracts. However these may not be profit maximising, and the banks may choose contracts with the property that runs will occur with positive probability.

[3] Chari and Jagannathan (1988) emphasise the panic aspect of this type of runs. A portion of the depositors, uninformed about the true values of their bank's assets, can only learn about the state of the bank by observing its queue for withdrawals. However they cannot distinguish whether there is a long queue because of consumption needs or because informed depositors are getting out early. They may then infer (correctly or not) that the bank is about to fail and withdraw.

In the model presented here we make use of the interim information structure of Jacklin and Bhattacharya, while following Diamond and Dybvig in assuming corner preferences for the consumers, as they either care about early or late consumption. This provides an environment where sunspot panics and information based bank runs co-exist. To this framework we add Cooper and Ross's (1991) extension with respect to the early liquidation of the bank's illiquid investments.[4] By doing so, we demonstrate the important role of banks in providing liquidity, a feature that is not clearly brought out by the original Diamond and Dybvig model. Furthermore, we take the sequential service constraint seriously by assuming the spatial separation of agents in the economy.[5] This constraint makes contracts with consumption payments contingent on the total number of agents

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[4] Diamond and Dybvig consider the role of liquidity in their model, but their liquid investment technology (storage) is completely dominated by the illiquid one. This is because they assume that early liquidation of the long-term productive technology results to a payoff equal to the initial investment in the technology, thus matching the service that storage provides. Cooper and Ross modify the model to study the importance of salvage value more carefully.

[5] No justification for the existence of the sequential service constraint was originally given in the model of Diamond and Dybvig, until Wallace (1988) suggested the spatial separation of agents. Calomiris and Kahn (1991) also noted that the first-come first-served rule warrants explanation, after comparing this property with the analogous situation of bankrupt firms, but recognised it as a rule and explained it as compensation for those who choose to invest in information and as a tool that eliminates the resulting free-rider problem.

in queue inconsistent. Without the first-come first-served assumption, panics would not take place and the model would not reflect the history of banking. Its omission would also lead to the establishment of an efficient early credit market, inconsistent with voluntary participation in an illiquid banking arrangement.[6] Diamond and Dybvig's paper, although discussing the sequential service constraint, did not fully explain or respect it when considering the policy of deposit insurance as an answer to uncertainty over the aggregate level of early withdrawals.[7]

Allen and Gale (1998) present a model with similar characteristics in order to study financial crises. They adapt the information-based view of bank runs, however discard the assumption of first-come first-served, and at the same time study the consequences of liquidation costs indirectly, by assuming that the return to storage by early withdrawing late consumers is lower than the return obtained by the bank. In our model, we respect the sequential service constraint, and study the consequences of liquidation costs directly, by considering the salvage value of long-term illiquid investments.

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[6] Banking can be seen as a substitute for market activity in a world where agents are isolated. Without isolation, the outcome obtained by the intermediary can also be obtained by the credit market and therefore there is no role for banks. See Jacklin (1987).

[7] We study the possibility of aggregate risk over consumption timing in Chapter 5.

We begin by presenting a slightly altered version of the Diamond and Dybvig model of liquidity insurance. We then present our model, which includes a number of modifications in order to address problems ignored by the original presentation of Diamond and Dybvig.[8] In particular, we stress the advantage of our model in offering an environment where sunspot panics coexist with information-based bank runs.

3.2 Liquidity Insurance and the Diamond and Dybvig Model

Consider an environment where people live for three periods (time T=0, which is the planning period, times T=1 and T=2, which are the consumption periods). There is a continuum of ex-ante identical agents whose measure is normalised to one. Agents are endowed in the planning period with one unit of the single commodity that exists in this economy. They maximise utility of consumption, but are uncertain about their consumption timing. With probability π they derive utility from early consumption in period T=1, and with probability $(1-\pi)$ they

[8] In our model, both sunspot panics and information-based bank runs exist, we allow for low salvage values of the long-term technology and take

prefer late consumption in period T=2. Their utility function $u(c_T)$, where c_T denotes consumption in date T, is assumed to be increasing, strictly concave and twice continuously differentiable.

The good can either be left in storage at no cost or be invested in a long-term technology that yields R>1 in the last period of the model, but returns only one unit if liquidated prematurely in an earlier period.[9]

Under autarky agents can store their individual endowments or invest them in the long-term technology. Note that this provides no insurance against their intertemporal preference shock. They will maximise the following expected utility in ex-ante terms:

$$U_A^{D\&D} = \pi u(c_1) + \rho(1-\pi)u(c_2) \qquad (1)$$

where $\rho \leq 1$ is a discount factor, subject to the following constraints:

$$\begin{aligned} c_1 &= 1 - I + I \\ c_2 &= 1 - I + IR = 1 + I(R-1) \end{aligned} \qquad (2)$$

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the sequential service constraint seriously.

where I denotes the proportion of the good invested during the planning period in the long-term technology. Since the premature liquidation of the long-term technology yields the same amount as storage, it is optimal for the agents to invest everything in the illiquid yet productive technology ($I=1$) and liquidate in the unlucky outcome that they are early consumers.[10]

A bank, by pooling together investors' resources can provide insurance against depositor's preference shock. Consumers become depositors by surrendering their inherited units of goods to the bank and the bank promises a non-stochastic consumption profile corresponding to the solution of the following program:

$$U_B^{D\&D} = \pi u(c_1) + \rho(1-\pi)u(c_2) \tag{3}$$

subject to:

[9] We could also represent storage as a liquid asset with constant returns to scale that takes one unit of good in period T and converts it into one unit of good in period T+1, where T=0,1.

[10] In Appendix 3.1, we show that in this specific environment a market economy (where agents are permitted to trade) achieves the same ex-ante utility as autarky. A small modification can however change our results significantly. If the premature liquidation of the long-term technology returns less than storage, the market economy Pareto dominates the autarky allocation.

$$\begin{matrix} \pi c_1 = 1 - I \\ (1-\pi)c_2 = IR \end{matrix} \Rightarrow \pi c_1 + \frac{(1-\pi)c_2}{R} = 1 \tag{4}$$

where the solution (c_1, c_2) can be interpreted as a deposit contract.

The optimal allocation satisfies the following first order condition:

$$\frac{u'(c_1)}{u'(c_2)} = \rho R \qquad \text{or} \qquad c_2 > c_1 \tag{5}$$

ensuring that late consumers will never want to imitate early consumers. In other words the contract offered by the bank is incentive compatible (the incentive constraint is not binding and has no impact on the optimal allocation).

It is immediately obvious that the banking contract performs at least as well as autarky, since the consumption bundle (c_1, c_2)=(1,R) is feasible and incentive compatible. However the bank can do even better than this in terms of ex-ante expected utility. Assuming a relative risk aversion greater than one we get:

$$u'(1) > \rho R u'(R) \tag{6}$$

showing that the outcome of autarky can be improved by increasing period T=1 consumption and decreasing period T=2 consumption:

$$c_1 > 1 \text{ and } c_2 < R \qquad (7)$$

With this model Diamond and Dybvig made an important advance in the theory of banking by providing a micro-economic model of maturity matching and insurance providing against agents' uncertain liquidity preference. Furthermore they showed how this Pareto optimal mechanism can be subject to banking panics, the result of multiple equilibria.

Under the 'good' equilibrium, the one we have been considering so far, the bank maximises the consumer's welfare and provides optimal liquidity insurance. Under the 'bad' equilibrium late consumers decide to withdraw early imitating the early consumers. This occurs because it is rational for each consumer to pull his money out, if he expects that the other investors will behave in the same way. Because of the illiquidity of the long-term investment, the bank cannot honour all its liabilities if all agents present them for redemption, and given the existence of a sequential service constraint (first-come first-served), if a panic was to take place the agents at the end of the queue would suffer losses, receiving less than promised.[11] In order to avoid incurring such losses, they will choose to step to the head of the queue, causing the very event they imagined. If everyone decides to run we get a self-fulfilling panic.

Our work deviates from that of Diamond and Dybvig in three important ways. Firstly, they consider risk in terms of an illiquid long-term asset. By introducing uncertainty over its return we will also have to consider the possibility of information-based runs, thus complicating policies like suspension of deposit convertibility that could eliminate sunspot panics. We consider such issues in Chapter 4. Furthermore, Diamond and Dybvig assume that the proportion of early consumers is known with certainty at the aggregate level. We study the possibility of aggregate uncertainty over consumption time preference in Chapter 5. Finally the Diamond and Dybvig model concentrates in a domestic economy. We study the implications of the addition of a currency market in Chapter 6.

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[11] We raise again Cooper and Ross's concern over the true illiquidity of the long-term technology in Diamond and Dybvig's model. Although Diamond and Dybvig discuss the issue of illiquidity in their model, storage is completely dominated by the 'illiquid' technology, whose premature liquidation yields the same result as storage. Cooper and Ross argue that Diamond and Dybvig's model demonstrates the insurance aspect of banking, but not the bank's role in providing liquidity. In our basic model we

3.3 General Framework

Like Diamond and Dybvig our model has three periods (T=0, 1, 2) and a continuum of agents whose measure is normalized to one, each endowed with one unit of good at T=0. These agents are ex-ante identical, and each faces a privately observed, uninsurable risk of being impatient (cares only about consumption in T=1) or patient (cares only about consumption in T=2). The liquidity shock is independently and identically distributed: with probability π they are early consumers, with $(1-\pi)$ late. Their types are revealed to them in period T=1.

Consumption goods can be stored from one period to the next at no cost. Alternatively, and similarly to Jacklin and Bhattacharya, there is a long-lived productive technology, whose return is a random variable. At T=0, with probability θ the return in T=2 is low R_l, and with probability $(1-\theta)$ it is high R_h.

In contrast to Jacklin and Bhattacharya and in accordance with Cooper and Ross, we attempt to capture the irreversibility of this long-term investment by assuming that each unit of liquidation in T=1 yields only $(1-\tau)$, where $\tau \in [0,1]$.[12] Diamond

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incorporate Cooper and Ross's modifications to demonstrate this important aspect of intermediation.

[12] We will need to impose some restrictions on the parameter τ as we progress with the analysis of the model (see footnote 17).

and Dybvig assumed $\tau = 0$, thus ignoring early liquidation costs, while Jacklin and Bhattacharya at the other extreme assumed $\tau = 1$, a zero return and thus complete irreversibility.

One option is for agents to live in autarky. The ex-ante expected utility of an agent choosing autarky will be:

$$U_A = \pi u(c_1) + \rho(1-\pi)[\theta u(c_{2l}) + (1-\theta)u(c_{2h})] \tag{8}$$

subject to:

$$\begin{aligned} c_1 &= 1 - I + (1-\tau)I \\ c_{2l} &= 1 - I + IR_l \\ c_{2h} &= 1 - I + IR_h \end{aligned} \tag{9}$$

Under autarky, and given our assumption of an illiquid long-term technology, this contract can lead to the inefficient premature liquidation of the economy's investments, since it fails to provide insurance against the agents' inherent uncertainty over their consumption timing.[13]

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[13] A market economy can offer better allocations than autarky (see Appendix 3.1). For a comparison between market outcomes and deposit contracts see Jacklin (1987), who observes that some form of market incompleteness is required for explaining the existence of banking, and Jacklin and Bhattacharya, who study the choice between deposit and equity. Jacklin and Bhattacharya show that non-traded deposit contracts may or may not be preferred to traded equity type contracts depending on the riskiness

Following Diamond and Dybvig, banks will design optimal contracts to provide insurance against agents' liquidity shock. We assume a sequential service constraint, which implies that contracts with consumption payments contingent on the total number of agents in line are inconsistent. To justify the constraint, we follow Wallace in assuming spatial separation of agents. If consumers are assumed to be isolated, then they will be prevented from co-ordinating their withdrawals.[14]

Consider program P, which solves for the first best:

$$\underset{c,I}{Max}\, U_P = \pi u(c_1) + \rho(1-\pi)[\theta u(c_{2l}) + (1-\theta)u(c_{2h})] \qquad (10)$$

subject to:

$$\begin{aligned} \pi c_1 &= 1 - I \\ (1-\pi)c_{2l} &= IR_l \\ (1-\pi)c_{2h} &= IR_h \end{aligned} \qquad (11)$$

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of the underlying assets and on the nature and availability of information about these assets.

[14] From a historical point of view, this was interpreted by Bhattacharya and Gale (1987) as a large number of geographically separated banks in the US due to prohibitions of interstate banking. Wallace's suggestion about the spatial separation can then be used to explain the shock needed to cause sunspot panics. As Chari (1989) points out the source for such variations in the demand for currency can be the agricultural community in the countryside. The nature of the banking system in the US

where $\rho \leq 1$ is the discount factor, I is the amount invested in the risky illiquid technology, c_1 is the consumption promised to early consumers and c_{2l}, c_{2h} the consumption allocated to late consumers conditional on the realized return of the long-term investment.

P provides the solution for the case when the consumer's type is publicly observable in T=1. Alternatively, it may be that the consumer's type is not observable, but under specific values of the exogenous variables a patient consumer would have no incentive to run. That is when the following expression is satisfied:

$$\theta u(c_{2l}) + (1-\theta)u(c_{2h}) \geq u(c_1) \qquad (12)$$

If this expression is not satisfied, it will have to be added to P as an incentive compatibility constraint.[15]

It is also important to make sure that the technology considered is efficient, productive and thus desirable for investment by the consumers:

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with reserve pyramiding would then cause country banks to behave as individual depositors withdrawing their reserves from city banks.

[15] This will not be necessary for our model as we claim shortly.

$$\theta u(R_l) + (1-\theta)u(R_h) > u(1) \tag{13}$$

The expected utility from investing in the risky technology must be greater than that obtained from storage.

3.4 The Contract

Let the utility function take the form $u(c) = \frac{c^{1-\gamma}}{1-\gamma}$, representing preferences with a relative risk aversion parameter γ. We follow Jacklin and Bhattacharya in restricting the parameter to $0 \le \gamma < 1$.

Also, following Jacklin and Bhattacharya, we give the following characteristics to the bank's contract: if $\tilde{R} = R_h$ the bank pays a promised return c_2, and if $\tilde{R} = R_l$ it pays R_l/R_h of this promised return. The modified optimisation problem P looks like this:

$$Max U_P = \pi \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi)A\frac{c_2^{1-\gamma}}{1-\gamma} \tag{14}$$

where $A=(1-\theta)+\theta(\frac{R_l}{R_h})^{1-\gamma}$, subject to:

$$\begin{matrix} \pi c_1 = 1-I \\ (1-\pi)c_2 = R_h I \end{matrix} \Rightarrow \pi c_1 + \frac{(1-\pi)c_2}{R_h} - 1 = 0 \qquad (15)$$

which is the budget constraint of this program.

We will now introduce an important assumption about the exogenous variables in this model. We assume $A(\rho R_h)^{1-\gamma} > 1$ for $\gamma < 1$. This implies that we do not need to consider the incentive compatibility constraint. Even more importantly it ensures that we are not forcing the risk-averse consumers to accept a contract built on a technology that they would otherwise choose not to invest in. These claims are considered in Appendices 3.2 and 3.3 respectively.

The first order conditions are:

$$\begin{aligned} &\pi c_1^{-\gamma} - \lambda\pi = 0 \\ &\rho(1-\pi)Ac_2^{-\gamma} - \lambda\frac{(1-\pi)}{R_h} = 0 \Rightarrow \rho A R_h c_2^{-\gamma} = c_1^{-\gamma} \\ &\pi c_1 + \frac{(1-\pi)c_2}{R_h} - 1 = 0 \end{aligned} \qquad (16)$$

where λ is the Lagrange multiplier associated with the budget constraint.

Solving we get:

$$c_1 = \frac{1}{\pi + (1-\pi)\dfrac{(\rho A R_h)^{1/\gamma}}{R_h}}$$

$$c_2 = (\rho A R_h)^{1/\gamma} c_1 \tag{17}$$

which form the basis for the contract between the bank and the depositors.[16]

[16] We need to impose the following restriction on the parameter τ:

$$(1-\tau) \leq \frac{1}{\pi + (1-\pi)\dfrac{(\rho A R_h)^{1/\gamma}}{R_h}} = c_1$$

This is necessary in order to ensure that the choice between storage and the long-term technology is not trivial. If the premature liquidation of the investment was to yield more than the bank's promised allocation for period T=1, storage would be completely dominated.

3.5 Sunspot Panics and Information-Based Bank Runs

Suppose that suspension of convertibility is not available. As in Diamond and Dybvig, sunspot panics exist under such a contract. Banks are maturity transformers that take liquid deposits and invest part of the proceeds in illiquid assets. In doing so they pool risk and enhance welfare, but also create the possibility of self-fulfilling bank runs, a second equilibrium of the game which is inefficient. Because of the illiquidity of the long-term investment, a bank cannot honour all its liabilities at par if all creditors suddenly withdraw their loans. Under the 'bad' equilibrium, it becomes rational for each creditor to pull his money out from a solvent borrower in T=1 if he expects that the other investors will behave in the same way. Given the existence of a sequential service constraint, if a panic was to take place the agents at the end of the line would receive less than promised due to low salvage values from premature liquidation. In order to avoid incurring such losses, they will choose to step to the front of the line, causing the very event they imagined. The bank's assets do not match demand and the bank fails and shuts down. Consumers' expectations prove to be self-fulfilling and the possibility of inefficient sunspot panics arises.

Diamond and Dybvig identified the suspension of convertibility as a mechanism that can eliminate the Pareto-inferior equilibrium of the bank's standard demand deposit contract. The implications of this policy for our specified environment are studied in Chapter 4.

In this model sunspot panics coexist with information-based runs. At T=1 agents receive information and update their probability assessment for $\widetilde{R} = R_l$ from θ to θ^N.[17] This revised probability may make patient consumers to prefer the payment intended for impatient consumers. Define:

$$\hat{A} = (1 - \hat{\theta}) + \hat{\theta}(\frac{R_l}{R_h})^{1-\gamma} \tag{18}$$

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[17] This informational update can be the source of a significant problem with the design of the bank contract. Jacklin and Bhattacharya assumed that the bank is not aware of the possibility of bank runs due to interim updates in information regarding the return of the long-term investment. If banks were fully informed, they could design a contract to prevent runs by incorporating the worse possible informational update. Alonso (1996) took up the task of solving for this scenario. He showed that these run-proof contracts are possible, but not necessarily optimal ex-ante. Alonso demonstrated that banks may sometimes choose contracts subject to runs and the rationale behind such behaviour is that to let an event with very low probability (the receival of the worse possible information) to affect the whole allocation (as would happen in the design of a run-proof contract incorporating the low probability worse possible information scenario) might be worse in ex-ante utility terms than the contract that allows for runs. We demonstrate that Alonso's results stand in our

We want to find the critical value $\hat{\theta}$ above which patient consumers will choose to misrepresent their type. This will happen when:

$$\hat{A}\,\frac{c_2^{\,1-\gamma}}{1-\gamma} < \frac{c_1^{\,1-\gamma}}{1-\gamma} \tag{19}$$

implying:

$$\hat{\theta} > \frac{(\frac{c_1}{c_2})^{1-\gamma} - 1}{(\frac{R_l}{R_h})^{1-\gamma} - 1} = \frac{\frac{1}{(\rho A R_h)^{1-\gamma/\gamma}} - 1}{(\frac{R_l}{R_h})^{1-\gamma} - 1} \tag{20}$$

Proof that $\hat{\theta}$ is above θ is given in Appendix 3.5.

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environment in Appendix 3.4 and, for our analysis, we restrict theta values accordingly to exclude cases where run-proof contracts are optimal.

3.6 Review of The Model's Timing and Information Availability and Structure

At this point it is worth reviewing the basic model's timing and the information availability and structure, since these assumptions are crucial for the models in each of the Chapters that follow.

Decisions are made during time periods T=0 and T=1. During time period T=0, the bank offers a contract which defines an agreement between a depositor and the bank.[18] According to this contract, the depositor who accepts must give up his endowment of the good in period T=0 in exchange for a riskless amount of period T=1 goods or a high but risky amount of period T=2 goods. Period T=2 goods are the product of an investment whose performance expectations are shared among all agents in the model.

During the transition from period T=0 and T=1 nature determines each depositors' type (either early or late

[18] Note that although each consumer faces a privately observed, uninsurable risk of being impatient (with probability π) or patient (with probability $(1-\pi)$), at the aggregate level this uncertainty is resolved. A proportion π, of the continuum of ex-ante identical consumers whose measure is normalised to one, will derive utility by consuming in the first period, while a proportion $(1-\pi)$ will derive utility by consuming in the

consumption) and reveals it to each individual depositor and noone else (other depositors or the bank). Nature also produces an update regarding the state of the investment, revealed to both the bank's depositors and the bank.

Early consumers will attempt to withdraw with certainty in period T=1, since they derive utility from consuming in period T=1 only. Whether they will be successful in obtaining a consumption allocation depends on the late consumers' decision and on the policies followed by the government. The crucial decision of late consumers is whether to withdraw in period T=1 and store until consumption in period T=2 or withdraw and consume in period T=2. Their decision depends (a) in the case of sunspot panics on their belief about other late consumers' reaction and the policy followed by the government, while (b) in the case of information based bank runs it will depend on the informational update that nature produces regarding the risky investment during the transition from period T=1 to T=2.

This structure is common in all Chapters. Whenever we need to add to the information structure or the decision process (for example by allowing for many banks or taking into account the possibility of currency crises) we will do so explicitly in the context of the relevant Chapter.

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last period of the model. This property is common knowledge and allows a bank to provide insurance against the consumers' liquidity shock.

3.7 Discussion

The influential work of Diamond and Dybvig argued that bank contracts can be optimal and nevertheless lead to costly panics. The original model did however suffer from a number of difficulties related to its hypotheses.

Cooper and Ross pointed out that although the banks in Diamond and Dybvig's paper did provide insurance to agents against the unlucky outcome of being an early consumer, they did not provide liquidity to the economy. We incorporate the changes introduced by Cooper and Ross in order to make the investment choice between storage and the long-term illiquid technology a non-trivial one.

We also assume the spatial separation of agents in the economy and pay particular attention in respecting the sequential service constraint, also known as the first-come first-served constraint, which stems from this assumption. Diamond and Dybvig were criticised by Wallace for violating this constraint while studying deposit insurance, a policy to battle uncertainty of early withdrawals at the aggregate level. We study aggregate uncertainty of consumption timing in Chapter 5 and assume the spatial separation throughout our study. We also avoid writing contracts contingent on the number of early withdrawals, as this would be a clear violation of the sequential service constraint.

Perhaps the most important feature of our basic model is the co-existence of sunspot panics and information-based bank runs. If we accept that both types of banking crises are possible (see Section 2.1.6 for the empirical evidence on this subject), then any policy considerations must be based on a model that is capable of illustrating aspects of panics and runs. In Chapter 4 we study suspension of convertibility and its desirability in such an environment.

In Chapter 6 we offer an extension to the Diamond and Dybvig model that opens up the domestic economy model by adding a currency market. Kaminsky and Reinhart (1996) document the simultaneous occurrence of balance of payments and banking crises and point to the importance of their joint study. Nevertheless, their empirical study offers no light on the direction of causation. Our results highlight that the trigger of twin crises can originate at either part of the economy.

Appendix 3.1

Consider the possibility of trade in the Diamond and Dybvig environment, by opening a financial market in T=1. Late consuming agents can now trade the good that they left in storage for the rights to the long-term technology that the early consumers hold. Similarly, early consuming agents can trade their rights to the long-term technology in exchange for the good that was left in storage by the late consumers. Let P denote the price attached to the rights of one unit of good in period T=2.

Ex-ante identical agents will maximise the following expected utility:

$$U_M^{D\&D} = \pi u(c_1) + \rho(1-\pi)u(c_2) \tag{21}$$

subject to:

$$\begin{aligned} c_1 &= 1 - I + PIR \\ c_2 &= \frac{1-I}{P} + IR \end{aligned} \tag{22}$$

The equilibrium allocation for the market economy in this variant of the Diamond and Dybvig model is $c_1 = 1$, $c_2 = R$,

$P=\frac{1}{R}$.[19] Note that the market allocation is the same as the autarky one, since the premature liquidation of the long-term technology yields the same return as storage, making the choice between storage and productive technology under autarky trivial.

If we alter the autarky case to consider lower possible values for premature liquidation of the long-term technology we get considerably different results. Let each unit of liquidation of the long-term technology in T=1 yield only $(1-\tau)$, where $\tau\in[0,1]$.[20]

Under autarky agents now maximise ex-ante utility as given by (1) subject to the following constraints:

$$\begin{aligned} c_1 &= 1-I+I(1-\tau)\leq 1 \\ c_2 &= 1-I+IR=1+I(R-1)\leq R \end{aligned} \tag{23}$$

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[19] To see why the price P of one unit of T=2 good in period T=1 (thus the price of the long-term technology in T=1) is $P=\frac{1}{R}$, consider the two possible alternatives. If $P>\frac{1}{R}$ then the long-term investment dominates the storage option and early consumers will be offering the long-term investment for sale but there will be no buyers, making the price to fall to $P=0$. Similarly, if $P<\frac{1}{R}$, no one will invest in the long-term investment in period T=0 and when consumers try to buy it in period T=1 the price will soar to $P=\infty$.

[20] We also make this assumption in our basic model. Note that Diamond and Dybvig assumed $\tau=0$, thus ignoring early liquidation costs.

In this case the allocation under a market economy is Pareto superior to autarky, since there is no inefficient premature liquidation of the illiquid long-term investment. Nevertheless, the market economy is not Pareto optimal, unlike the allocation achieved under banking arrangements. See Freixas and Rochet (1998) for a detailed exposition.

Appendix 3.2

The expression that needs to be satisfied for a viable contract is $A\frac{c_2^{1-\gamma}}{1-\gamma} \geq \frac{c_1^{1-\gamma}}{1-\gamma}$. From the first order condition in expression (17) we have that $c_2 = (\rho A R_h)^{1/\gamma} c_1$.

Plugging the one expression into the other gives $A(\rho R_h)^{1-\gamma} > 1$ for $\gamma < 1$. This is the assumption used so that the need for including incentive compatibility constraints will not arise. Notice that this assumption occurs naturally as we show in Appendix 3.3.

Appendix 3.3

Let us consider the constraint imposed more carefully. We do this for $\gamma < 1$:

$$A(\rho R_h)^{1-\gamma} > 1 \tag{24}$$

where $A = (1-\theta) + \theta(\frac{R_l}{R_h})^{1-\gamma}$. If we substitute for A:

$$\begin{aligned} &[(1-\theta) + \theta(\frac{R_l}{R_h})^{1-\gamma}](\rho R_h)^{1-\gamma} > 1 \\ &[(1-\theta)R_h^{1-\gamma} + \theta R_l^{1-\gamma}]\rho^{1-\gamma} > 1 \end{aligned} \tag{25}$$

Now also consider when the available technology will be preferred to storage by the risk-averse investors:

$$[(1-\theta)\frac{R_h^{1-\gamma}}{1-\gamma} + \theta\frac{R_l^{1-\gamma}}{1-\gamma}]\rho > \frac{1^{1-\gamma}}{1-\gamma}\rho \Leftrightarrow [(1-\theta)R_h^{1-\gamma} + \theta R_l^{1-\gamma}] > 1 \tag{26}$$

That is the expected utility derived from investing in the risky technology must be greater from the utility from storage.

As ρ approaches one then expressions (25) and (26) converge. Thus the assumption made ensures that the technology is not forced on the risk-averse consumers by the design of the contract, but it is seen as productive, efficient and an investment that they would choose to invest in.

Appendix 3.4

We follow Alonso in assuming that the interim informational update takes the form of a signal s indicating the return of the long-term technology through an updated probability of a low return θ_s.

Let $\theta = z\theta_1 + (1-z)\theta_2$, where $\theta_1 > \theta_2$. In other words, in period T=0 it is known that with probability z the interim information will update the probability of a low return to θ_1 (i.e. $s=1$), while with probability $(1-z)$ the interim information will update the probability of a low return to θ_2 (i.e. $s=2$), where the signal $s=1$ corresponds to the worse possible scenario.

Just like Alonso and Jacklin and Bhattacharya we assume that the contract cannot be conditioned on s. The run-proof contract will then satisfy the optimisation problem as given by (14), subject to the budget constraint (15) and the additional 'no-run even in the worse case scenario' constraint $A_1 \frac{c_2^{1-\gamma}}{1-\gamma} \geq \frac{c_1^{1-\gamma}}{1-\gamma}$,

where $A_1 = (1-\theta_1) + \theta_1 (\frac{R_l}{R_h})^{1-\gamma}$.

Since θ_1 is the worse possible informational update, the inclusion of this constraint in the maximization program ensures that late consumers will never prefer the early consumer's allocation over theirs and will never cause an information-based bank run. To differentiate between the solutions of the two contracts, we attach the capital letter A as subscript to the solutions of the run-proof program.

The true ex-ante utilities of these two contracts, given the above information structure, will be:

$$U_{TP} = (1-z)\left[\pi \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi) A_2 \frac{c_2^{1-\gamma}}{1-\gamma}\right] + z\left[\pi \frac{c_L^{1-\gamma}}{1-\gamma} + \rho(1-\pi)\frac{c_L^{1-\gamma}}{1-\gamma}\right] \quad (27)$$

for the contract subject to runs, where $A_2 = (1-\theta_2) + \theta_2 (\frac{R_l}{R_h})^{1-\gamma}$ and $c_L = 1 - I + (1-\tau) I$ (we assume that the interim update is received by all agents, in which case the bank will expect an information-based bank run, will liquidate all investments and will distribute all funds equally among all depositors), and:

$$U_{TA} = (1-z)\left[\pi\frac{c_{1A}{}^{1-\gamma}}{1-\gamma} + \rho(1-\pi)A_2\frac{c_{2A}{}^{1-\gamma}}{1-\gamma}\right] + z\left[\pi\frac{c_{1A}{}^{1-\gamma}}{1-\gamma} + \rho(1-\pi)A_1\frac{c_{2A}{}^{1-\gamma}}{1-\gamma}\right] \tag{28}$$

for the run-proof contract.

Comparing the true ex-ante utilities we can derive the critical information level θ_1^A above which the true ex-ante utility of the contract subject to runs is higher than the true ex-ante utility of the run-proof contract:

$$\begin{aligned} & U_{TP} > U_{TA} \\ & \Leftrightarrow \pi\frac{c_L{}^{1-\gamma}}{1-\gamma} + \rho(1-\pi)\frac{c_L{}^{1-\gamma}}{1-\gamma} > \pi\frac{c_{1A}{}^{1-\gamma}}{1-\gamma} + \rho(1-\pi)A_1{}^A\frac{c_{2A}{}^{1-\gamma}}{1-\gamma} \\ & \Leftrightarrow \theta_1{}^A > \frac{\left[\frac{(\pi+\rho(1-\pi))c_L{}^{1-\gamma} - \pi c_{1A}{}^{1-\gamma}}{\rho(1-\pi)c_{2A}{}^{1-\gamma}}\right] - 1}{\left(\frac{R_l}{R_h}\right)^{1-\gamma} - 1} \end{aligned} \tag{29}$$

where $A_1{}^A = (1-\theta_1{}^A) + \theta_1{}^A(\frac{R_l}{R_h})^{1-\gamma}$.

This result matches expectations since a high θ_1^A implies a low probability z of the worse possible outcome materializing. In that case, the run-proof contract, which allows a very low probability event to affect the whole allocation, will be worse in ex-ante utility terms compared to the contract subject to runs. To allow for contracts subject to runs in the text, we need to assume that $\theta \geq \theta_1^A$.

To provide a numerical example let $\theta = 0.5$, $\theta_1 = 0.9$, $z = 0.2$, $\pi = 0.5$, $\gamma = 0.5$, $\rho = 0.9$, $R_h = 2$, $R_l = 0.5$ and $\tau = 0.3$. In that case, the run-proof contract offers allocations $c_1 = 0.75$ and $c_2 = 2.49$ by investing $I = 0.62$, and achieves a true expected ex-ante utility of $U_{TA} = 1.93$. Alternatively, the contract subject to runs offers allocations $c_1 = 1.05$ and $c_2 = 1.91$ by investing $I = 0.48$, distributes $c_L = 0.86$ in case of an expected information-based run and achieves a true expected ex-ante utility of $U_{TP} = 1.97 > U_{TA}$, satisfying the assumption $A(\rho R_h)^{1-\gamma} = 1.006 > 1$.

Appendix 3.5

Notice that $\theta = \dfrac{A-1}{(\frac{R_l}{R_h})^{1-\gamma} - 1}$. To prove that $\hat{\theta} > \theta$, substitute for $\hat{\theta}$ and θ:

$$\frac{(\frac{c_1}{c_2})^{1-\gamma} - 1}{(\frac{R_l}{R_h})^{1-\gamma} - 1} > \frac{A-1}{(\frac{R_l}{R_h})^{1-\gamma} - 1} \tag{30}$$

leading to the necessary and sufficient condition:

$$A\frac{c_2^{1-\gamma}}{1-\gamma} \geq \frac{c_1^{1-\gamma}}{1-\gamma} \tag{31}$$

which is satisfied, since our initial assumption of $A(\rho R_h)^{1-\gamma} > 1$ for $\gamma < 1$ is derived from this condition. This is shown in Appendix 3.2.

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CHAPTER 4

Suspension of Convertibility: Contagion and Policy Dilemmas

4.1 Introduction

Suspending deposit convertibility can be seen as a violation of a bank's contractual obligations to holders of its demandable debt. Recent events in Argentina (December 2001) illustrate this argument. When faced with an increased number of withdrawals, the Argentinean government imposed a partial, followed by full, suspension of convertibility, a measure that was greeted with fierce criticism, questioning its legality, leading to riots, violence and a procession of presidents-for-a-day.[1]

In this Chapter we use the basic model laid out in Chapter 3 to study economic arguments for and against suspension of

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[1] Such suspensions at the national or state level occurred in the US in August 1814, Fall 1819, May 1837, October 1839, October 1857, September 1873, July 1893, October 1907 and March 1933, according to Sprague (1910) and Friedman and Schwartz (1963).

deposit convertibility. Diamond and Dybvig (1983) have shown that such a policy, when stated explicitly and in advance, can eliminate bank failures from random withdrawal risk, termed as sunspot panics. Nevertheless, in an environment vulnerable to information-based runs a strict rule of suspension may not be optimal. Imposing such a restriction removes the advantage of discretionary liquidation of the long-term technology, which may be desirable if future returns are expected to be low, and eliminates the signalling property of suspension, which may limit contagion to the rest of the banks in the economy.[2]

Since suspension of convertibility is subject to such a trade-off, policy makers should turn to the empirical evidence studying the causes of bank failures before deciding on the implementation of such a strict rule. We offer an alternative solution to this dilemma, by exploiting the middle ground between discretion and rules. We show that discretion based on rules may be the optimal policy independent of the empirical studies' conclusions.

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[2] We also ask whether the crisis is solitary or systemic, what is the interest of the depositors, what should be the speed of reaction, and deal with issues of confidentiality, and concerns about interference with the market forces, matters that are central to the resolution of banking crises according to the Bank of England Handbook in Central Banking (Latter (1997), p. 25).

Suspension of convertibility is central to the issue of bank runs and panics. Diamond and Dybvig identified suspension of convertibility as a mechanism that can eliminate the Pareto-inferior equilibrium of the bank's standard demand deposit contract.[3] Jacklin and Bhattacharya (1988), by restricting withdrawals to specific proportions also make this assumption indirectly.[4]

Engineer (1989) shows that in a four-period version of the Diamond and Dybvig model, the policy of suspending deposit convertibility is not as effective and may not eliminate the bank run equilibrium, which can occur even if the bank can adjust new withdrawal payments after observing a high number of withdrawals. Gorton (1985), in an environment of incomplete information about the bank's investments, portrays a bank's suspension of convertibility as a signal to depositors that continuation of the long-term investments is mutually beneficial. Selgin (1993) shows that bank suspension contracts may be a

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[3] This assumes that aggregate consumption demand is certain. If withdrawals are stochastic however, a bank-run will be averted but optimal risk sharing will not be achieved. We study uncertainty over consumption timing at the aggregate level in Chapter 5.

[4] In Chari and Jagannathan (1988) suspension of convertibility is crucial for the existence of their bank contract and in yielding superior allocations to the market equilibrium in terms of ex-ante expected utility, leaving however ex-post some individuals worse off than others.

low-cost alternative to deposit insurance given the absence of regulatory interference.

In terms of welfare, following an information-based bank run, we find that the early liquidation of the long-term technology may be the best reaction if the future value of the bank's investments is expected to be extremely low. However, if a strict rule of suspension of convertibility is followed by the government, such optimal reaction may not be an option. This leads to considerable losses to depositors and would explain the bad reputation of suspension of payments.[5]

We also choose to abstract from the inter-bank market as the medium of contagion, in order to study information as a propagation mechanism of banking crises.[6] In recent years, an emerging empirical literature has focused on the nature of contagion. The evidence generally supports the information-based approach to panics, and we consider a number of these studies in Section 4.4.

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[5] Such losses motivated the violent events in Argentina in 2001 and led to the creation of the Federal Reserve in 1913.

[6] Theoretical papers on the benefits of inter-bank markets and the diversification of stochastic liquidity risk include Bhattacharya and Gale (1987), Bhattacharya and Fulgieri (1994) and Chari (1989). Theoretical papers on contagion through inter-bank links include Rochet and Tirole (1996), Freixas et al (2000), Allen and Gale (2000). An alternative approach on inter-bank co-ordination, with stochastic liquidity shocks coexisting with asset risk shocks, is presented in Koppl and MacGee (2001).

Theoretical papers that break away from the traditional inter-bank propagation mechanism are those of Bougheas (1999) and Chen (1999). Bougheas presents an overlapping generations model based on Jacklin and Bhattacharya, where bank failures become contagious only when the depressed state of the economy signals that the asset returns across the banking system are positively correlated. Chen, alternatively, concentrates on the importance of the number of failed banks acting as a signal about the prospects of the banking industry. Chen's analysis is similar to ours in two ways. We both assume that the timing of revelation about the health of long-term investments is different for different banks, although they all receive a privately observed signal within the intermediate period, after investment decisions have been made, but before full maturity of their projects is reached. Furthermore, we both term as panic the decision made from depositors to react to early information (the number of failed banks in Chen's model, a bank run and the government's reaction in our model) and not wait for more bank specific information.

We show how the government's reaction, given a choice of suspending deposit convertibility, to an information-based bank run, sends a crucial signal to the depositors of the rest of the banks in the economy regarding the state of their banks' investments. Under a rule of suspension of convertibility, such signalling is unavailable and contagious panic may cause the failure of solvent banks.

Given a rule of suspension of convertibility, sunspot panics are eliminated, but no early liquidation of bad performing assets is allowed (even if it is optimal to follow such a strategy), and no signals regarding the state of the economy's investments can be sent to panicking depositors of other banks in the economy (even though this may mitigate contagion). Regarding the optimality of a rule of suspension, the answer depends on the empirical evidence on the causes of bank failures. If sunspot panics dominate the banking sector, a rule of suspension is optimal. Otherwise discretion should be applied. We offer an alternative policy, that is not contingent on the conclusions offered by empirical studies, by setting up rules for a discretionary policy to be implemented explicitly and in advance.

Building on the basic model of Chapter 3, we present the advantages (elimination of sunspot panics) and drawbacks (first in terms of welfare and then in terms of contagion control) of the unconditional suspension of convertibility rule. This is followed by a consideration of the available empirical evidence on sunspot panics and information based bank runs in an attempt to offer a solution to the dilemma that this trade-off presents, before we put forward our suggestion for optimal policy making.

4.2 Rules vs. Discretion: Welfare Comparisons

Under a policy of suspension of deposit convertibility, the government is obliged to suspend payments following the observation of a run or panic to a bank. This eliminates the possibility of sunspot panics, but has two important drawbacks following an information-based run. It removes the advantage of discretionary liquidation of the long-term technology, which may be optimal for the depositor's welfare (studied in this Section), and eliminates the signalling property of suspension, which may limit contagion to the rest of the banks in the economy (studied in Section 4.3).

Using the basic model of Chapter 3, we consider and compare the ex-post welfare of depositors under the two possible states. If no suspension takes place, the bank will fail by liquidating its long-term investments in order to make payments to all depositors withdrawing. If suspension of deposit convertibility is in place, early liquidation of the illiquid long-term investments is not allowed and the bank is kept alive by forbidding excess withdrawals in period T=1.

We first analyse the case where the government does not suspend deposit convertibility when an information-based run takes place. In that case full liquidation of the long-term illiquid technology takes place and the proceeds are distributed to withdrawing depositors in an equal basis. The ex-post utility level achieved is:

$$U_{NSoC} = \pi \frac{c_L^{1-\gamma}}{1-\gamma} + \rho(1-\pi)\frac{c_L^{1-\gamma}}{1-\gamma} \tag{32}$$

where $c_L = 1 - I + (1-\tau)I$.

If alternatively the government suspended deposit convertibility following the receival of the informational update $\theta^N > \hat{\theta}$ and the information-based run, liquidation of the long-term illiquid investments would not be allowed. As late consumers run to the bank because of their preference for the early consumer's allocation, they give up their rights to the period T=2 promised allocations. We assume that under this scenario, all available resources for distribution in the last period of our model are distributed equally among early consumers who received nothing in period T=1 and late consumers withdrawing in T=2, that is a total of $(1-\pi)$ consumers.[7] Early consumers receive no utility from this allocation.

[7] Just like in normal times of no runs, $(1-\pi)$ consumers withdraw in period T=2, but, unlike normal times, the composition of this mass changes in the case of a run. Instead of only late consumers, the mass now consists of early and late consumers.

To derive the ex-post utility level under suspension of convertibility consider the following: For the π people receiving c_1 in period T=1, a proportion π of them will be early consumers and $(1-\pi)$ of them will be late consumers. From the $(1-\pi)$ people receiving c_2 with probability $(1-\theta^N)$ and $\frac{R_l}{R_h}c_2$ with probability θ^N, $(\pi-\pi^2)$ will be early and $(1-\pi)-\pi(1-\pi)$ will be late. Thus:

$$U_{SoC} = \pi^2 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho\pi(1-\pi)\frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi)^2 A^N \frac{c_2^{1-\gamma}}{1-\gamma} \tag{33}$$

where $A^N = 1-\theta^N + \theta^N\left(\frac{R_l}{R_h}\right)^{1-\gamma}$.

We can now find the critical value of information $\overline{\theta}$ below which suspension of convertibility is optimal and thus $U_{NSoC} < U_{SoC}$. Let $\overline{A} = 1-\overline{\theta} + \overline{\theta}(\frac{R_l}{R_h})^{1-\gamma}$ and substitute for U_{SoC}:

$$\begin{aligned} & U_{NSoC} < U_{SoC} \\ & \Leftrightarrow \overline{\theta} < \frac{B-1}{(\frac{R_l}{R_h})^{1-\gamma}-1} \end{aligned} \tag{34}$$

where:

$$B = \frac{U_{NSoC} - [\pi^2 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho\pi(1-\pi)\frac{c_1^{1-\gamma}}{1-\gamma}]}{\rho(1-\pi)^2 \frac{c_2^{1-\gamma}}{1-\gamma}} \tag{35}$$

For $\theta^N > \bar{\theta}$ the optimal reaction to an information-based run is to avoid suspension of deposit convertibility. This result matches expectations, since it is sensible to suspend convertibility when the investments are worth saving (low values of bad information), while for worse information and lower expected returns from the investments, the liquidation value is preferred.

The government will act in the interest of the depositors of the bank that is about to fail, and its reaction will be crucial for the future of the bank. Our findings suggest that, for lower values of bad information, suspension of convertibility will be preferred, since the portfolio investments are in a relative good state and it is worth avoiding their premature liquidation. This is achieved by keeping the bank alive. For higher values of realized θ^N the optimal policy will be to avoid suspending deposit convertibility, thus allowing the early liquidation of the long-term investments and the failure of the bank. This follows from the belief that the portfolio investments are in a bad state and not worth saving.

However, under an explicit and pre-announced rule of suspension of convertibility the option of liquidation is not available. Thus, when considering information-based runs, our ex-post welfare analysis suggests that a discretionary approach to suspension of convertibility would be optimal.

4.3 Information-Based Contagious Panics

We now study the possibility of contagion, the effect of suspending deposit convertibility on the economy, the optimal speed of the government's reaction and issues of confidentiality. We particularly point out the importance of suspension of convertibility as a signalling mechanism to the depositors of banks in the rest of the economy. We show that, if discretion is followed, suspending convertibility may save the local region from contagious panic effects, associated with an assumed positive correlation in the returns of investments in the region.

Suppose that banks in the economy diversify risk by investing in a number of investment projects. Portfolios exhibit ex-ante the same return and risk characteristics and there exists a positive, yet not perfect, correlation in the returns of portfolio investments. Furthermore, assume that the timing of information revelation about portfolio investments' returns is different for different banks, although all banks receive a privately observed signal within the intermediate period, after investment decisions have been made, but before full maturity of their projects is reached.

The depositors of the rest of the banks in the economy, observing the run in one bank, will update their beliefs about the return of their own banks' portfolios, since they know that investments in the economy are positively correlated, and will have to make a decision about making their own withdrawals. They will base their decision on how bad they believe the information received about the portfolio investments of the bank that is experiencing the run was, and how closely correlated their bank's investments are to the one that is failing.

Consider the process that the late consumers of the rest of the banks in the economy use to make their choice between early and late withdrawal. Assume initially that they observe the exact updated information ($\theta^N \geq \theta$) that caused the run in the bank in trouble, and that they know the exact correlation of returns (r) between their bank and the one that is experiencing the run. Then, the updating mechanism, which will be used to revise the probability of a bad return from their previous belief θ to the updated value $\tilde{\theta}$, is:

$$\tilde{\theta} = r\theta^N \tag{36}$$

With perfect information, depositors will be able to revise efficiently the probability of a low return for their bank's long-term investment and decide whether to run or not. They will compare this value to the critical value above which they would prefer the allocation intended for early consumers.

We now drop the assumption that they observe the exact signal that caused the run in the bank in trouble. From their knowledge of the occurrence of a bank run, depositors of the rest of the banks in the economy can make an important inference. The information received by the depositors of the troubled bank must have induced them to update their probability of a bad return from their bank's investment above the critical value $\hat{\theta}$ given by (20). Thus, the value of the realized θ^N must lie somewhere between $\hat{\theta}$ and 1. The updating mechanism takes the following form in this case:

$$\tilde{\theta}' = r \int_{\theta^N = \hat{\theta}}^{\theta^N = 1} \eta \theta^N d\theta^N \qquad (37)$$

where we assume that θ^N can take any value over the interval $[\hat{\theta},1]$ and η stands for the conditional probability attached to the possible values of θ^N, given that it lies inside the above interval.

Depositors will compare this value to the critical value above which they would prefer the allocation intended for early consumers and decide whether to run or not. We call their decision to withdraw, under the given circumstances, contagious panic, as it will be based not on information about their own bank's specific returns, but on the observation of a run in another bank.

Due to this uncertainty in the decision making process of the depositors, we argue that the government's reaction to the run will send an important signal about the health of investments in the economy, crucial in determining the spread of the contagion.[8]

If the government reacted by suspending deposit convertibility, depositors could safely assume that this was done because the long-term investment was in a relatively good state and was worth saving from early liquidation.[9] As we showed earlier in this Section, this will be the case when $\theta^N < \bar{\theta}$,

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[8] Unlike the depositors of other banks, we assume that the government learns the exact state of the portfolio of the bank under attack. This is a reasonable assumption, since it is normal for authorities to gain access to the balance sheets of banks in trouble, before decisions regarding intervention are made.

[9] We assume that the government will not suspend convertibility to influence and avert depositors of other banks in the economy from withdrawing early, but will only suspend if it finds it optimal and in the interest of the troubled bank's depositors to do so. We make this choice, because in a longer horizon model with repeated interactions, consistency would become important, and such behaviour would be inefficient and undesirable. Furthermore we could assume that the responsibility of suspending deposit convertibility could be assigned to an independent body,

changing the higher limit of the possible values that θ^N may take. Note that $\bar{\theta}$ is less than one. The updating mechanism is transformed in the following way:

$$\tilde{\theta}'' = r \int_{\theta^N = \hat{\theta}}^{\theta^N = \bar{\theta}} \eta' \theta^N d\theta^N \qquad (38)$$

where θ^N can take any value over the interval $[\hat{\theta}, \bar{\theta}]$ and η stands for the conditional probability attached to the possible values of θ^N, given that it lays inside the above interval.

The consequence is that $\tilde{\theta}'' < \tilde{\theta}'$. Suspension of convertibility has the effect of lowering depositors' beliefs about the probability of a low return for their banks' long-term investments. Thus, contagion by panic, in an economy where a positive correlation of asset return exists, is minimized by the observation of suspension.

Depositors of banks with portfolio investments of a high positive correlation to the investments of the bank that is experiencing the run will choose to withdraw immediately. However, depositors of banks with lower degrees of correlation, will face greater uncertainty about their bank's portfolio returns and the observation of suspension of convertibility will become

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not constrained by political considerations and focusing on the long-term important in their decision making. Such a reaction by the government will signal a relatively good state of the investments of the bank under attack, and thus they may choose not to run, since there is a high probability that their bank's portfolio is in a good state. Thus, the reaction of the government to a bank run becomes crucial to the decision making process of the depositors of other banks, and may save the economy from a contagious panic.

The speed of the government's reaction becomes crucial as well. If the government decides to suspend deposit convertibility, the announcement of such a policy should take place immediately, in order to affect the beliefs of depositors as early as possible. Without this information, depositors may believe that the portfolio investments of their banks are in a worse condition than they may actually be, and this may result to more panics against solvent banks in the economy.

Issues of confidentiality are also relevant to our analysis. It could be argued that the government should make available information on the exact state of the troubled bank's portfolio investments, and allow all banks with low portfolio returns to fail. However the bank runs are not caused by expectations that banks will not honour their contracts. Instead late consumers choose to withdraw early and misrepresent their type, because

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stability of the banking system.

they find that ex-post they prefer the allocation promised to early consumers. For this reason, the government has the right to secrecy in order to prevent such runs. Nevertheless, if the information to be made public suggested a state of the investments better than the one that would be inferred by the simple observation of a suspension of convertibility, it may be optimal to allow public access to all information about the bank experiencing the run.

4.4 Optimal Policy

Since an explicitly pre-announced rule of suspension of deposit convertibility presents such serious drawbacks in an environment where information-based bank runs are present, its implementation should depend on the probability that such events take place in the real world.

Despite the importance for policy making of answering the question on the causes of bank failures, not much empirical work has been done in the field. Deposit behaviour has been studied by Park (1991), Saunders and Wilson (1996), Calomiris and Mason (1997) and Schumacher (2000). Park shows that bank failures are contagious due to the lack of bank-specific information and that depositors make withdrawal decisions based on the condition of the banking system as a whole. Calomiris and Mason also find that asymmetric information between depositors and banks can precipitate a general run of banks. Saunders and Wilson results are consistent with the presence of a significant number of informed depositors who distinguish among ex ante failing and non-failing banks. Schumacher, just like the previous studies, supports the information-based theory approach, while also noting the importance of spillover effects that the suspensions of troubled banks have on similar banks.

Aharony and Swary (1996) undertake an empirical study on contagious bank failures, which further supports our view that the failure of one bank will have an important impact on banks that are perceived by depositors as having similar portfolios to the one held by the failed bank. They use three observable bank characteristics as the interim private information that depositors may use for their assessment of the riskiness of their bank's long-lived assets: the geographical distance of the solvent bank's headquarters from the headquarters of the failed banks (a short distance suggests a high similarity of loan portfolio composition), the size of solvent banks (similar size indicates similarity in the type of business in which banks engage) and the capital ratio (as a proxy for solvency). Studying five large-bank failures in the Southwest region of the US during the mid-1980's, their findings (distance and capital adequacy negatively related to the magnitude of the contagion effect, whereas size positively related) are consistent with an information-based contagion hypothesis and motivate our choice for this particular channel of contagion.

Aharony and Swary (1983), Swary (1986), Karafiath et al. (1991) also make use of bank stock returns to make inferences about the causes of bank contagion. These studies largely support the information-based view of bank runs, which meets further approval by Gorton (1988), Calomiris and Gorton (1991) and Donaldson (1992), that stress the importance of economic shocks for banking crises.

Despite the evidence pointing to an information-based view of the banking sector panics, policy makers must remain cautious regarding their decisions. We offer an alternative to the extremes of having a strict rule or pure discretion when considering the policy of suspension of deposit convertibility.

Suppose that the government makes explicit ex-ante that for all runs and panics there will be an immediate suspension of convertibility, but for one exception to this rule. If the future profits of the troubled bank are predicted to be extremely low, liquidation will be allowed and the bank will fail.

Sunspot panics are eliminated, and discretion can be followed in the case of an information-based run. If liquidation of the long-term investment is optimal, which will be the case when the illiquid investment is predicted to yield low returns in the future, the bank will be closed down. If future returns are expected to be relatively good, suspension takes place and a signal that it is worth keeping long-term investments and banks alive is sent to depositors across the economy. In our view, this is the optimal policy regarding suspension of convertibility and has the additional advantage that it is not contingent on the policy makers' beliefs on the causes of bank failures.

4.5 Discussion

The question on the cause of banking panics and runs is an empirical one and remains largely unanswered. This uncertainty would suggest that policy makers have to consider the importance of both sunspot panics and information-based runs. In this model we consider an environment where sunspot panics and information-based runs may co-exist, while we respect the sequential service constraint and we take into account the importance of liquidation costs. We find that the existence of suspension of convertibility as a policy, although it has the effect of eliminating the random withdrawal risk that causes sunspot panics, it may not be optimal in an environment vulnerable to information-based runs. Imposing such a restrictive rule removes the advantage of discretionary liquidation of the long-term technology, which may be optimal if future bank profits are expected to be low, and eliminates the signalling property of suspension, which may limit contagion to the rest of the banks in an economy.

By comparing the ex-post depositors' utilities with and without suspension following an information-based run, we find that a pre-announced explicit rule of suspension is not always optimal. We show that suspension of convertibility is optimal if the evaluation of future bank profits is relatively optimistic, while for worse information about portfolio returns full liquidation should be allowed. Furthermore, suspending deposit convertibility in a world of policy discretion and where banks share similar portfolio-return characteristics could lessen the contagious effect of panics, by signalling a low value of bad information.

If we accept that both sunspot and information-based banking crises are possible, then this model would suggest that the ex-ante commitment to suspension of convertibility can be too restrictive and should receive more thought, since its welfare implications depend on the type of the crisis.

We offer an alternative solution to the trade-off problem that the rule of suspension of deposit convertibility presents, a solution that is independent of the empirical evidence on the type of bank failures.

A discretionary policy of suspension of deposit convertibility may be the best option if based on specific pre-announced rules. The ex-ante announcement of suspension of convertibility in all instances, except than when the bank's future expected returns are predicted to be extremely low, would eliminate the rationale of sunspot panics and would allow liquidation of long-term investments when this is optimal following an information-based run. Suspension following an information-based run would also lessen the contagious effect of panic, by signalling a not-so-bad state of the economy's investments.

An interesting extension to this model would be to study the structure of correlation knowledge among banks. Allen and Gale (2000) consider the structure of interregional claims among banks for their study on contagion. We could study the importance of similar structures, using our method of analysis. Disconnected and incomplete structures would then become crucial for determining the spread of an information-based contagion panic.

It would also be interesting to compare the costs and effectiveness of suspension of deposit convertibility versus deposit insurance in mitigating contagious panic in the banking sector. Deposit insurance emerges as a mechanism to remove the incentive for early withdrawal under bank panics caused by asymmetric information about the condition of banks. Calomiris and Masson (1997) note that if the risk of solvent banks failing under an asymmetric information panic is not high, then a federal safety net might not be desirable. They identify inter-bank cooperation as a mechanism for reducing the risk of failure of solvent banks. In this Chapter we have shown that the announcement of suspension of convertibility can have a similar effect. Thus such a policy could also present an alternative to costly deposit insurance and would be worth investigating.

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CHAPTER 5

Aggregate Uncertainty about Consumption Time Preference: In Search of the Optimal Solution

5.1 Introduction

One basic function of banks is to provide consumers with liquidity insurance. Diamond and Dybvig (1983) show how intermediaries can facilitate agents' uncertainty over the timing of their future consumption needs by the provision of deposit contracts. In addition, they demonstrate how these contracts can be both optimal and lead to banking panics.

In an environment where long-term investments are illiquid (in the sense that in the event of early liquidation only fire-sale prices are obtainable), agents with inherent uncertainty about consumption time preference turn to banks to insure against the unlucky outcome of being early consumers. When backed by a policy of suspension of convertibility, the deposit contracts offered by the intermediaries provide optimal risk sharing, without the possibility of sunspot panics.[1] However, the intermediaries' insurance provision and the panic-free environment that the suspension of deposit convertibility ensures, crucially depend on the assumption that at the aggregate there is no uncertainty, meaning that the time pattern of aggregate consumption is predictable.

In this Chapter we ask what happens when uncertainty over the timing of consumption is not eliminated at the aggregate level.

We show that Wallace's (1988) result that contracts with consumption allocations contingent on the order of withdrawal can do better in terms of ex-ante utility when compared to contracts that do not form such dependencies remains valid even in a richer environment, that includes storage possibilities and fire-sale prices following the premature liquidation of investments in long-term technologies.[2] We also note that such contracts are subject to inefficiencies, since they involve either excess storage, premature liquidations or a combination of the two.

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[1] Nevertheless suspension of deposit convertibility does not eliminate information-based bank runs. See Chapter 4.

[2] This result depends on the assumption that it is impossible to form an inter-bank arrangement. If inter-bank coordination is possible, a contract based on borrowing and lending among banks will be the optimal solution to the aggregate uncertainty problem under the conditions set in our environment.

Furthermore, following Bhattacharya and Gale (1987), we study the design of inter-bank cooperation contracts, under which borrowing and lending takes place between participating banks in order to resolve aggregate uncertainty over the proportion of early withdrawals. In contrast to Bhattacharya and Gale's paper we choose to respect the first-come first-served constraint and we show that in our environment this borrowing-lending solution is the best feasible arrangement and is not subject to second-best distortions, arising due to binding incentive compatibility constraints. We also note that, in contrast to Wallace's solutions as laid out in our richer environment, an inter-bank arrangement does not face excess storage or premature liquidation inefficiencies.

Diamond and Dybvig identify the possibility of aggregate risk and try to resolve the issue by considering government deposit insurance. Despite the proportion of early consumers being stochastic, they argue that such a policy will achieve the optimal risk sharing as a unique Nash equilibrium. The mechanism they identify can also be described as a tax. This tax is applied to early withdrawers ex-post, after the proportion of early consumers has been observed, and redistributes wealth so that all allocation promises are guaranteed credibly. This redistribution of wealth eliminates late consumers' incentive to withdraw early, and it provides the first-best risk sharing arrangement. The implementation of the policy is costless, since the need for it will never arise in the first place if it is credible.

Nevertheless, the design of this mechanism is flawed. Wallace stresses that such an ex-post arrangement ignores the sequential service constraint assumed throughout the rest of the Diamond and Dybvig model.[3] The sequential service constraint, also known as the first-come first-served condition, requires that the bank service withdrawers in the order and at the time of arrival at the bank's counters. In doing so, the option of observing the total number of early withdrawers and subsequently deciding on the allocation to be distributed is not permitted. The redistributing tax associated with deposit insurance necessitates the observation of the proportion of early withdrawers and this contingency is not feasible if the sequential service constraint is to be taken seriously. Even if the government can tax depositors after withdrawals, there is no guarantee that depositors have not already consumed. Wallace goes on to show that the best arrangement that can be achieved in the presence of aggregate uncertainty must form a dependency of early consumption in the order by which early withdrawers approach the bank. He points out that he does not provide the first-best solution to the

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[3] See Section 2.1.3 on why the sequential service constraint is a realistic and essential part of the mechanism that produces sunspot panics

aggregate risk problem, but simply demonstrates that contracts with this dependency-property dominate all other feasible arrangements.[4]

Bhattacharya and Gale provide an alternative solution to the aggregate risk problem, by re-interpreting the economic environment facing early withdrawal risk. Consider a number of spatially separated intermediaries subject to privately observed shocks regarding the proportion of early withdrawals they face.[5] If we assume that these regional liquidity shocks are imperfectly correlated, we can design an inter-bank co-ordination mechanism to insure all participating members.[6] Since the investment decision of each member-bank is unobservable, central to the

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and on how Wallace (1988) was the first paper that addressed the issue by assuming the spatial separation of agents in the economy.

[4] Wallace (1990) illustrates this dependency for a special case of aggregate risk. In an environment where a small amount of aggregate risk is limited to a group of early withdrawers who appear last in the queue, he shows that partial suspension is the best feasible arrangement: when the late-to-show-up group want to withdraw, they get less than those who withdrew earlier.

[5] Chari (1989) interprets this as community risk, where the source of variation in the demand for money could be explained by shocks faced by the agricultural community in the countryside.

[6] Bhattacharya and Fulghieri (1994) analyse a model of inter-bank coordination where banks face timing uncertainty in the return on their short-term investments. Theoretical research on inter-bank coordination has also concentrated on contagion through inter-bank links. Papers include Rochet and Tirole (1996), Freixas et al (2000), Allen and Gale (2000). Discussions on such arrangements are provided by Calomiris (1990), Gorton (1985) and Williamson (1989).

design of such a contract is the inclusion of incentive compatibility constraints to avoid the inherent moral hazard. Bhattacharya and Gale show that these second-best distortions restrict the inter-bank arrangement and prevent it from achieving the optimal result.

Nevertheless, Bhattacharya and Gale's system of borrowing and lending among banks has a similar flaw to the one demonstrated by Wallace for the Diamond and Dybvig model. The sequential service constraint has not been taken seriously in the design of the inter-bank arrangements, which specify promised early consumption allocations contingent on the total withdrawals faced by the individual bank.

When the first depositor will show up for withdrawal, the bank will be unable to determine which consumption allocation best suits its liquidity pattern, since the total number of early withdrawals can only be determined by an observation to be made further down the queue. Respecting the sequential service constraint in an inter-bank arrangement necessitates one common early consumption allocation promise by all banks, regardless of their unforeseen early withdrawal rate.

In our environment, contrary to Bhattacharya and Gale's results, we find that inter-bank coordination can supply the optimal contract under the restrictions imposed by the sequential service constraint.

We first lay out the general framework of our economy. Just like in the basic model of Chapter 3, the Diamond and Dybvig model of the bank's provision of liquidity has been altered to respect the sequential service constraint and take salvage value of the long-term illiquid investments into account. However, we choose to abstract from the possibility of information based runs, as this would only complicate the nature of the offered contracts without adding further insight to the issue in study. We present and compare three distinct contracts, trying to resolve uncertainty over the proportion of early withdrawals. The Late Full Suspension contract (Section 5.3) corresponds to Wallace's contract of non-contingency on the order of withdrawals. The Early Partial Suspension (Section 5.4) forms such a dependency in our richer environment. The Inter-Bank Coordination contract (Section 5.5) alters the Bhattacharya and Gale model to respect the sequential service constraint.

5.2 General Framework

We use a similar framework to that of the basic model of Chapter 3. We alter the Diamond and Dybvig model to include the possibility of low liquidation values for the long-term technology (see Cooper and Ross (1991)) and take the sequential service constraint seriously in the design of contracts (see Wallace).

One difference in comparison to the basic model is that the long-term technology is not risky in terms of the return it yields in period T=2.[7] To include this feature would only complicate the three alternative solutions to the problem of aggregate uncertainty, without adding anything to our analysis (see Appendix 5.4 for more on this issue).

In the basic model we assumed, just like in Jacklin and Bhattacharya (1988), that there is a long-term productive technology, whose return was a random variable. At T=0 with probability θ the return in T=2 was low R_l, and with probability $(1-\theta)$ it was high R_h. We now revert to a similar asset to the one postulated in Diamond and Dybvig by assuming a long-term

[7] Thus the information structure related to the risky long-term investment is no longer relevant in this Chapter.

technology that yields R>1 in the last period of the model.[8] But, unlike Diamond and Dybvig and in the spirit of Cooper and Ross, we retain the basic model assumption that this investment opportunity is truly illiquid, thus each unit of liquidation in T=1 yields only $(1-\tau)$, where $\tau \in [0,1]$.[9]

We further introduce the possibility of random withdrawals at the aggregate level. In the basic model ex-ante identical agents faced a privately observed, uninsurable risk of being impatient or patient consumers. With probability π they derived utility from early consumption in period T=1, and with probability $(1-\pi)$ they preferred late consumption in period T=2.

In this Chapter we assume that banks can not predict with certainty the proportion of consumers that will demand the allocation promised for distribution in period T=1. Suppose that with probability ϕ the proportion of early consumers will be π_1,

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[8] A crucial difference between our and Diamond and Dybvig's model, other than the fire-sale prices resulting from the premature liquidation of the long-term technology, is the existence of storage.

[9] We also impose the following restriction on the parameter τ:

$$(1-\tau) \leq c_1$$

where c_1 stands for the bank's period T=1 allocation promise to depositors under each of the contracts we present in this Chapter. This is necessary in order to ensure that the choice between storage and the long-term technology is not trivial. If the premature liquidation of the investment was to yield more than the bank's promised allocation for period T=1, storage would be completely dominated.

while with probability $(1-\phi)$ this proportion will be π_2, where $\pi_2 > \pi_1$.

We compare three distinct contracts.[10] Note that all of them involve some type of suspension of convertibility. This ensures that these contracts do not face the possibility of sunspot panics, which would make any comparison trivial, due to the impossibility of assigning a probability to such bank failures.[11]

[10] We also describe and compare autarky against these models in Appendix 5.1. For ease of exposition of this Chapter's results, Appendix 5.3 presents two more possible, yet sub-optimal in terms of ex-ante utility, contracts. The first one considers a contract written for the highest possible number of early withdrawals (π_2), implying the storage of goods from period T=1 to T=2 if the low proportion of early consumers arises. In contrast, the second contract is based on the lowest possible number of early withdrawals (π_1), allowing for the liquidation of the long-term technology if the high proportion of early consumers arises.

[11] Note that information based runs, although not studied in this Section, are still possible. Thus these contracts do not appear unrealistic in a world that does experience banking system failures.

5.3 Late Full Suspension of Convertibility: A Non-Contingent Contract

The late full suspension of convertibility case involves writing a contract that respects the sequential service constraint, takes advantage of storage, investment and liquidation options and is not contingent on the position of withdrawers in the queue.

We present the equivalent contract under Wallace's assumptions of no storage or costly liquidation in Appendix 5.2 and point out its main differences with the model presented here.

Late full suspension of convertibility is imposed after π_2 withdrawals in period T=1, assuring all late consumers that their allocations are not in risk of being prematurely liquidated and thus avoiding the possibility of sunspot panics. The reason for labelling this policy late suspension, is because it comes into effect after π_2 and not π_1 withdrawals of c_1, unlike the early partial suspension studied in the following section. This characteristic's consequences are further explained after the analysis of the early partial suspension policy.

We solve for contracts that respect the following conditions:

$$\begin{aligned} &\pi_2 c_1 \geq S \geq \pi_1 c_1 \\ &L \leq I \end{aligned} \qquad (39)$$

where S stands for the proportion of the good surrendered by depositors to the bank in T=1 and left in storage, I for the part that is invested in the productive, yet illiquid long-term investment and L for the part of that investment I that is prematurely liquidated in T=1. Storage can be greater or equal to what is needed to cover withdrawal demand fully in the case of low withdrawals, and less or equal than withdrawal demand in the case of high withdrawals. Liquidation must be less or equal to the full investment made in the planning period.

The ex-ante expected utility under late full suspension of convertibility will be:

$$MaxU_{FS} = \phi\left[\pi_1 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi_1)\frac{c_{21}^{1-\gamma}}{1-\gamma}\right] + (1-\phi)\left[\pi_2 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi_2)\frac{c_{22}^{1-\gamma}}{1-\gamma}\right] \quad (40)$$

subject to:

$$\begin{aligned}
&S + I = 1 \\
&\pi_1 c_1 \leq S \\
&(1-\pi_1)c_{21} = IR + (S - \pi_1 c_1) \Rightarrow I = \frac{\pi_1 c_1 + (1-\pi_1)c_{21} - 1}{R-1} \\
&\pi_2 c_1 = S + L(1-\tau) \Rightarrow L = \frac{\pi_2 c_1 + I - 1}{(1-\tau)} \\
&(1-\pi_2)c_{22} = (I - L)R
\end{aligned} \quad (41)$$

Part of the available good in the planning period is left in storage (S). If there is a low proportion (π_1) of early withdrawers, any excesses in storage ($S-\pi_1 c_1$) will be carried forward for consumption in period T=2. This excess in storage and the return from what was invested (RI) will be distributed to the remaining depositors ($1-\pi_1$) in period T=2. If a high number (π_2) of depositors withdraw early, then part of the investment in the productive long-term investment may be liquidated (L) at fire-sale prices ($1-\tau$) to meet excess withdrawal demand ($\pi_2 c_1$). This premature liquidation comes at the cost of consumption for the late consumers, but forms part of the initial contract that ensures an allocation for late withdrawers high enough so that no panics arise.

Note that $\pi_1 c_1 \leq 1-I$ is not binding and does not have to be included in the maximization program. Plugging L and I in the last of the constraints given by (41), yields the following budget constraint:

$$(B\pi_1+\pi_2)c_1+B(1-\pi_1)c_{21}+(1-\pi_2)c_{22}\frac{(1-\tau)}{R}=1+B \qquad (42)$$

where $B=\frac{1-(1-\tau)}{R-1}=\frac{\tau}{R-1}$.

The first order conditions of this program are:

$$(\phi\pi_1 + (1-\phi)\pi_2)c_1^{-\gamma} - \lambda(B\pi_1 + \pi_2) = 0 \Rightarrow \lambda = \frac{(\phi\pi_1 + (1-\phi)\pi_2)c_1^{-\gamma}}{(B\pi_1 + \pi_2)}$$

$$\phi\rho(1-\pi_1)c_{21}^{-\gamma} - \lambda B(1-\pi_1) = 0 \Rightarrow \lambda = \frac{\phi\rho c_{21}^{-\gamma}}{B} \tag{43}$$

$$(1-\phi)\rho(1-\pi_2)c_{22}^{-\gamma} - \lambda(1-\pi_2)\frac{(1-\tau)}{R} = 0 \Rightarrow \lambda = \frac{(1-\phi)\rho R c_{22}^{-\gamma}}{(1-\tau)}$$

where λ is the Lagrange multiplier associated with the budget constraint.

Solving we get:

$$c_1 = \frac{1+B}{B\pi_1 + \pi_2 + B(1-\pi_1)K_1 + (1-\pi_2)\frac{(1-\tau)}{R}K_2}$$

$$c_{21} = K_1 c_1 \tag{44}$$

$$c_{22} = K_2 c_1$$

where:

$$K_1 = \left[\frac{\phi\rho(B\pi_1 + \pi_2)}{B(\phi\pi_1 + (1-\phi)\pi_2)}\right]^{1/\gamma}$$

$$K_2 = \left[\frac{(1-\phi)\rho R(B\pi_1 + \pi_2)}{(1-\tau)(\phi\pi_1 + (1-\phi)\pi_2)}\right]^{1/\gamma} \tag{45}$$

forming the basis for the contract offered by the bank to the participating depositors.

This contract will be incentive compatible (there will be no incentive for late consumers to misrepresent their type and withdraw early due to their preference for the allocation promised to early withdrawers) iff:

$$\begin{aligned} \frac{c_{21}^{\ 1-\gamma}}{1-\gamma} \geq \frac{c_1^{\ 1-\gamma}}{1-\gamma} \\ \frac{c_{22}^{\ 1-\gamma}}{1-\gamma} \geq \frac{c_1^{\ 1-\gamma}}{1-\gamma} \end{aligned} \tag{46}$$

If these constraints are not satisfied we will have to make the necessary inclusions in the maximization problem.[12]

Three important remarks should be made about the late full suspension of convertibility contract. Firstly, it respects the sequential service constraint by imposing one common early allocation promise by the banks, not contingent on the total number of early withdrawals. The second feature is that the contract is not contingent on the order of withdrawals (it is not contingent on the position of the withdrawer in the queue). Finally, the program involves inefficiencies in the form of carrying forward excess good in the case of a low proportion of early withdrawals, and of premature liquidation of the productive technology in the case of a high proportion of early withdrawers.

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[12] But, as we will see later on, for the purpose of this study, we can restrict our analysis to parameter values such that these constraints are not binding without any consequences.

5.4 Early Partial Suspension of Convertibility: An Order-Contingent Contract

The early partial suspension of convertibility contract is similar to the late full suspension one in the sense that the sequential service constraint is respected and full advantage of all available options (storage, investment, liquidation) is allowed.[13] Unlike the late full suspension case we now allow for allocations to be contingent on the order of withdrawals (but not on the total number of withdrawals).

The program we solve for in this Section is termed early partial suspension of convertibility because the bank restricts distributions to $c_L < c_1$ after $\pi_1 (< \pi_2)$ early withdrawals of allocation c_1 have taken place, until full suspension after another $(\pi_2 - \pi_1)$ early withdrawals. The assumption $\pi_1 < \pi_2$ justifies the terms early and late applied to the two contracts. The reason for making this distinction explicit is explained when we compare the two contracts after the analysis of the early partial suspension policy. Note that suspension also ensures, just like in the late full suspension contract, that no sunspot panics are possible.

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[13] Just like in the full suspension case we consider contracts that respect the following two conditions:

$$\pi_2 c_1 \geq S \geq \pi_1 c_1$$
$$L \leq I$$

Consider the following program under early partial suspension of convertibility:

$$\begin{aligned} MaxU_{PS} &= \phi\left[\pi_1 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi_1)\frac{c_{21}^{1-\gamma}}{1-\gamma}\right] \\ &+ (1-\phi)\left[\pi_1 \frac{c_1^{1-\gamma}}{1-\gamma} + (\pi_2-\pi_1)\frac{c_L^{1-\gamma}}{1-\gamma} + \rho(1-\pi_2)\frac{c_{22}^{1-\gamma}}{1-\gamma}\right] \end{aligned} \tag{47}$$

subject to:

$$\begin{aligned} &S + I = 1 \\ &\pi_1 c_1 \le 1 - I \\ &(1-\pi_1)c_{21} = IR + (S - \pi_1 c_1) \Rightarrow I = \frac{\pi_1 c_1 + (1-\pi_1)c_{21} - 1}{R-1} \\ &\pi_1 c_1 + (\pi_2 - \pi_1)c_L = S + L(1-\tau) \Rightarrow L = \frac{\pi_1 c_1 + (\pi_2 - \pi_1)c_L + I - 1}{(1-\tau)} \\ &(1-\pi_2)c_{22} = (I - L)R \end{aligned} \tag{48}$$

The storage, investment and liquidation decisions are similar to the case of full suspension, only this time $(\pi_2 - \pi_1)$ withdrawers (last in the queue) will receive the alternative consumption bundle c_L, and not c_1.

Just like in the case of late full suspension, note that $\pi_1 c_1 \le 1 - I$ is not binding and does not have to be included in the maximization program. Plugging L and I in the last of the constraints given by (48), yields the following budget constraint:

$$(B\pi_1 + \pi_1)c_1 + B(1-\pi_1)c_{21} + (\pi_2 - \pi_1)c_L + (1-\pi_2)c_{22}\frac{(1-\tau)}{R} = 1 + B \quad (49)$$

where $B = \frac{1-(1-\tau)}{R-1}$. The first order conditions are:

$$\begin{aligned}
&(\phi\pi_1 + (1-\phi)\pi_1)c_1^{-\gamma} - \lambda(B\pi_1 + \pi_1) = 0 \Rightarrow \lambda = \frac{c_1^{-\gamma}}{B+1} \\
&\phi\rho(1-\pi_1)c_{21}^{-\gamma} - \lambda B(1-\pi_1) = 0 \Rightarrow \lambda = \frac{\phi\rho c_{21}^{-\gamma}}{B} \\
&(1-\phi)(\pi_2 - \pi_1)c_L^{-\gamma} - \lambda(\pi_2 - \pi_1) = 0 \Rightarrow \lambda = (1-\phi)c_L^{-\gamma} \\
&(1-\phi)\rho(1-\pi_2)c_{22}^{-\gamma} - \lambda(1-\pi_2)\frac{(1-\tau)}{R} = 0 \Rightarrow \lambda = \frac{(1-\phi)\rho R c_{22}^{-\gamma}}{(1-\tau)}
\end{aligned} \quad (50)$$

where λ is the Lagrange multiplier associated with the budget constraint.

The contract offered under Early Partial Suspension makes the following allocation promises:

$$\begin{aligned}
&c_1 = \frac{1+B}{(1+B)\pi_1 + B(1-\pi_1)M_1 + (\pi_2 - \pi_1)M_2 + (1-\pi_2)\frac{(1-\tau)}{R}M_3} \\
&c_{21} = M_1 c_1 \\
&c_L = M_2 c_1 \\
&c_{22} = M_3 c_1
\end{aligned} \quad (51)$$

where:

$$M_1 = \left[\frac{\phi\rho(B+1)}{B}\right]^{1/\gamma}$$
$$M_2 = \left[(1-\phi)(B+1)\right]^{1/\gamma} \qquad (52)$$
$$M_3 = \left[\frac{(1-\phi)\rho R(B+1)}{(1-\tau)}\right]^{1/\gamma}$$

The incentive compatibility constraints, guaranteeing that late consumers will not prefer the consumption bundles allocated to early consumers, are:

$$\frac{c_{21}^{1-\gamma}}{1-\gamma} \geq \frac{c_1^{1-\gamma}}{1-\gamma}$$
$$\frac{c_1^{1-\gamma}}{1-\gamma} \geq \frac{c_L^{1-\gamma}}{1-\gamma}$$
$$\frac{c_{22}^{1-\gamma}}{1-\gamma} \geq \frac{c_1^{1-\gamma}}{1-\gamma} \qquad (53)$$
$$\frac{c_{21}^{1-\gamma}}{1-\gamma} \geq \frac{c_L^{1-\gamma}}{1-\gamma}$$
$$\frac{c_{22}^{1-\gamma}}{1-\gamma} \geq \frac{c_L^{1-\gamma}}{1-\gamma}$$

If these conditions are not satisfied we will have to make the necessary inclusions of the binding constraints in the maximization problem.[14]

---

[14] See footnote 11. In particular, notice that $\frac{c_{22}^{1-\gamma}}{1-\gamma} \geq \frac{c_L^{1-\gamma}}{1-\gamma} \Rightarrow \frac{\rho R}{(1-\tau)} \geq 1$ is not binding since $(1-\tau) \leq 1$. This ensures that the cost imposed by the premature liquidation of the long-term technology

Just as we did for the late full suspension contract we note that the early partial suspension contract respects the sequential serviced constraint and involves inefficiencies in the form of excess storage in the planning period or premature liquidation of productive investments. However, unlike the late full suspension contract, this contract is contingent in the order of withdrawals.

It is worth noting that the full suspension contract involves paying out more of the good in T=1 than the partial suspension contract, which would appear as a paradox given their labelling. However this is an issue related to the timing of the suspension, making the terms early and late an essential addition to the description of these policies. The late full suspension contract suspends payments after π_2 withdrawals of the allocation c_1, unlike the early partial suspension, which partially suspends after only $\pi_1 < \pi_2$ withdrawals of c_1, before fully suspending payments after a further $\pi_2 - \pi_1$ withdrawals of the allocation c_L.

The late full suspension case can be re-interpreted as a sub-case of the early partial suspension one, since c_L can take the value c_1. This also implies that any deviation of the form $c_L \neq c_1$ as a solution to the early partial suspension contract will be ex-

---

on the allocations of patient consumers cannot be the cause of sunspot panics. If the premature liquidation was to result in $\frac{c_{22}^{1-\gamma}}{1-\gamma} \geq \frac{c_L^{1-\gamma}}{1-\gamma}$ the ante utility maximising and will dominate the late full suspension contract. We use a numerical example to demonstrate that such deviations are possible and that they provide higher utilities than contracts that do not make allowances for $c_L \neq c_1$.

Given that inter-bank arrangements are prohibited by exogenously imposed factors, we now present a numerical example that compares the performance of late full versus early partial suspension contracts. We wish to prove that Wallace's result that contracts that form dependencies in the order of withdrawals by allowing for the consumption allocation of the last $(\pi_2 - \pi_1)$ withdrawers to take the form $c_L \neq c_1$ are ex-ante welfare maximising when compared to contracts that don't allow for such contingencies.

Consider a contract written under the following conditions: $\phi = 0.7$, $\pi_1 = 0.7$, $\pi_2 = 0.9$, $\gamma = 0.5$, $R = 2.7$, $(1-\tau) = 0.3$ and $\rho = 0.9$.

Under late full suspension of convertibility the contract offered takes the following values: $c_1 = 0.69$, $c_{21} = 3.93$, $c_{22} = 9.91$. The storage, investment and premature liquidation plan is as follows: $S = 0.61$, $I = 0.39$ and $L = 0.02$. The ex-ante utility achieved is $U_{FS} = 2.18$.

Under early partial suspension of convertibility the promised consumption bundles are: $c_1 = 0.82$, $c_L = 0.15$, $c_{21} = 3.80$,

---

possibility of panics would arise.

$c_{22} = 9.6$. The corresponding allocations of the available good in the planning period are: $S = 0.58$, $I = 0.42$ and $L = 0.06$. The ex-ante utility achieved is $U_{PS} = 2.21$, achieving a better result than full suspension and proving that optimal deviations of the form $c_L \neq c_1$ do take place.[15]

[15] Our example respects the constraints set out by the following expressions: (39), (46) and (53). Expression (39) sets natural restrictions on the possible sizes of storage and liquidation. Expressions (46) and (53) require some further comments, since they represent the incentive compatibility constraints under full and partial suspension. The aim of our study is to prove that optimal deviations of the form $c_L \neq c_1$ do take place. To achieve this we can restrict our search to contracts where these constraints do not bind. To solve for contracts where the constraints bind would be a tedious exercise that would not enhance our understanding of the main issues.

5.5 Inter-Bank Arrangements

Following Bhattacharya and Gale we study the implementation of a borrowing-lending mechanism across heterogeneous intermediaries to insure depositors against variations in their liquidity requirements. Unlike the two contracts described so far in Sections 5.3 and 5.4 the inter-bank model does not involve inefficient excess storage or early premature liquidation. For this reason we would expect it to be the optimal arrangement.

However, due to second-best distortions, this optimal arrangement could be unachievable. Bhattacharya and Gale show that the private, and not publicly observed, shocks in terms of the proportion of depositors wishing to make early withdrawals result in a free-rider problem, with intermediaries under-investing in the liquid asset (storage). This results to second-best distortions, since incentive compatibility constraints must be included in the programming of a viable contract.

Nevertheless, we demonstrate that in our environment the inter-bank mechanism is optimal and incentive compatible.

Note that, unlike Bhattacharya and Gale, we choose to include a sequential service constraint, which rules out the possibility of contracts contingent on the proportion of early withdrawals. This implies that the consumption allocation promised to early consumers must be common among all banks. Yet, we allow for contingency on the order of withdrawals.

The inter-bank contract subject to the first-come first-served constraint is derived from the following optimisation program:

$$
\begin{aligned}
Max U_{IB} = {} & \phi\left[\pi_1 \frac{c_1{}^{1-\gamma}}{1-\gamma} + \rho(1-\pi_1)\frac{c_{12}{}^{1-\gamma}}{1-\gamma}\right] \\
& + (1-\phi)\left[\pi_1 \frac{c_1{}^{1-\gamma}}{1-\gamma} + (\pi_2-\pi_1)\frac{c_L{}^{1-\gamma}}{1-\gamma} + \rho(1-\pi_2)\frac{c_{22}{}^{1-\gamma}}{1-\gamma}\right]
\end{aligned}
\tag{54}
$$

subject to:

$$
\begin{aligned}
& \phi\pi_1 c_1 + (1-\phi)\pi_1 c_1 + (1-\phi)(\pi_2-\pi_1)c_L = 1 - I \\
& \quad \phi(1-\pi_1)c_{12} + (1-\phi)(1-\pi_2)c_{22} = IR
\end{aligned}
\Rightarrow
$$

$$
\phi\left[\pi_1 c_1 + \frac{(1-\pi_1)c_{12}}{R}\right] + (1-\phi)\left[\pi_1 c_1 + (\pi_2-\pi_1)c_L + \frac{(1-\pi_2)c_{22}}{R}\right] = 1 \tag{55}
$$

Storage will have to provide enough to cover π_1 early consumers of ϕ banks and π_2 early consumers of $(1-\phi)$ banks. Note that we allow for order contingency by letting the last $(\pi_2-\pi_1)$ withdrawers of the $(1-\phi)$ banks to receive c_L. The return of the long-term investment will have to match withdrawals of $(1-\pi_1)$ late consumers of ϕ of the banks and $(1-\pi_2)$ late consumers of $(1-\phi)$ banks.

The first order conditions are:

$$
\begin{aligned}
&\phi\pi_1 c_1^{-\gamma} + (1-\phi)\pi_1 c_1^{-\gamma} - \lambda[\phi\pi_1 + (1-\phi)\pi_1] = 0 \Rightarrow \lambda = c_1^{-\gamma} \\
&(1-\phi)(\pi_2 - \pi_1)c_L^{-\gamma} - \lambda(1-\phi)(\pi_2 - \pi_1) = 0 \Rightarrow \lambda = c_L^{-\gamma} \\
&\phi\rho(1-\pi_1)c_{12}^{-\gamma} - \frac{\lambda\phi(1-\pi_1)}{R} = 0 \Rightarrow \lambda = \rho R c_{12}^{-\gamma} \\
&(1-\phi)\rho(1-\pi_2)c_{22}^{-\gamma} - \frac{\lambda(1-\phi)(1-\pi_2)}{R} = 0 \Rightarrow \lambda = \rho R c_{22}^{-\gamma}
\end{aligned}
\tag{56}
$$

By combining the first two and the last two of the first order conditions we get:

$$
\begin{aligned}
&c_1 = c_L \\
&c_{12} = c_{22}
\end{aligned}
\tag{57}
$$

From now on we let $c_{12} = c_{22} = c_2$. Solving we get:

$$
\begin{aligned}
&c_1 = \frac{1}{[\phi\pi_1 + (1-\phi)\pi_2] + [\phi(1-\pi_1) + (1-\phi)(1-\pi_2)]\frac{(\rho R)^{1/\gamma}}{R}} \\
&c_2 = (\rho R)^{1/\gamma} c_1
\end{aligned}
\tag{58}
$$

implying that $\rho R \geq 1$ is the sufficient and necessary condition in order for the following incentive compatibility condition to be satisfied:

$$
\frac{c_2^{1-\gamma}}{1-\gamma} \geq \frac{c_1^{1-\gamma}}{1-\gamma} \tag{59}
$$

This constraint states that the expected utility from consumption in period T=2 must be preferred by late consumers to withdrawal in T=1 and storage until consumption in T=2.

We term banks with a low proportion of early withdrawers Type I, and banks with a high proportion of early withdrawers Type II. In order to study the incentive compatibility constraints set up to prevent banks from misrepresenting their types, it is useful to reinterpret the environment as one of borrowing and lending among banks.

Table 5.1: Aggregated Transfers at T=1

	Type I		Type II		Total
Storage:	$\phi(1-I)$	+	$(1-\phi)(1-I)$	=	$(1-I)$
Consume:	$\phi\pi_1 c_1$	+	$(1-\phi)\pi_2 c_1$	=	$(1-I)$
Excess/ Shortage:	$\phi(1-I)-\phi\pi_1 c_1$	+	$(1-\phi)\pi_2 c_1 - (1-\phi)(1-I)$	=	0
Extra that Type I holds in T=1 is passed on to Type II.					

Table 5.2: Aggregated Transfers at T=2					
	Type I		Type II		Total
Invest:	ϕIR	+	$(1-\phi)IR$	=	IR
Consume:	$\phi(1-\pi_1)c_2$	+	$(1-\phi)(1-\pi_2)c_2$	=	IR
Excess/ Shortage:	$\phi(1-\pi_1)c_2-\phi IR$	+	$(1-\phi)IR-(1-\phi)(1-\pi_2)c_2$	=	0
Extra that Type II holds in T=2 is passed on to Type I.					

Tables 5.1 and 5.2, give us the aggregated (the total of banks, distinguished only by type) transfer of funds between Type I and Type II banks. Note that all banks store and invest the same amounts in the planning period T=0. In period T=1 Type II banks have a shortage of funds, while Type I banks have an excess of funds. In period T=2 Type I banks have a shortage of funds, while Type II banks have an excess of funds. Therefore in period T=1 Type II banks will borrow from Type I, and by repaying in period T=2 they will cover the shortage of funds that Type I banks are subject to.

Table 5.3:

Individual Bank Transfers at T=1

	Type I	Type II
Storage:	$(1-I)$	$(1-I)$
Consume:	$\pi_1 c_1$	$\pi_2 c_1$
Excess/ Shortage:	$(1-I)-\pi_1 c_1$	$\pi_2 c_1 -(1-I)$

Table 5.4:

Individual Bank Transfers at T=2

	Type I	Type II
Invest:	IR	IR
Consume:	$(1-\pi_1)c_2$	$(1-\pi_2)c_2$
Excess/ Shortage:	$(1-\pi_1)c_2 - IR$	$IR-(1-\pi_2)c_2$

Alternatively, Tables 5.3 and 5.4 show the needs for and transfers of funds imposed by the inter-bank arrangement on individual banks. Note the relationship with the previous two tables. We can get the results for the individual banks by dividing the aggregated quantities by the mass ϕ of Type I and $(1-\phi)$ of Type II banks.

Let us now consider the possibility of banks breaking this inter-bank arrangement. If Type II banks decide to misrepresent their type and pass as Type I banks, they will have to give away $(1-I)-\pi_1 c_1$ in period T=1 in exchange of receiving $(1-\pi_1)c_2 - IR$ in period T=2. Thus they will pretend to be Type I iff:

$$\pi_2 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi_2)\frac{c_2^{1-\gamma}}{1-\gamma} \leq \pi_1 \frac{c_1^{1-\gamma}}{1-\gamma} + (\pi_2 - \pi_1)0 + \rho(1-\pi_2)\frac{\bar{c}_2^{1-\gamma}}{1-\gamma} \qquad (60)$$

where $\bar{c}_2 = \frac{(1-\pi_1)c_2}{(1-\pi_2)}$.[16]

Note that this misrepresentation implies that $(\pi_2 - \pi_1)$ of the early consumers will receive nothing for consumption. This poses two problems. Firstly, in Diamond and Dybvig based models the bank is interpreted as a collective of consumers. Therefore such a decision, implying zero utility for some members, would be unlikely. Moreover, given the specification of our utility function and a zero allocation for $(\pi_2 - \pi_1)$ of the early consumers in the case of cheating, even a small consumption increase in the proportion $(\pi_2 - \pi_1)$ of depositors that otherwise receive nothing, would dominate in terms of utility the increase

---

[16] $\bar{c}_2$ is derived by observing that $(1-\pi_1)c_2$ funds (that should under normal circumstances be available for a Type I bank) will be available for distribution among $(1-\pi_2)$ withdrawers in period T=2.

in utility that late consumers derive from the bank's misrepresentation.[17]

Consider next the possibility of a Type I bank imitating a Type II bank. In this case the bank will receive a subsidy in period T=1, but will have to give away part of its funds in period T=2. The bank will misrepresent its type iff:

$$\pi_1 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi_1)\frac{c_2^{1-\gamma}}{1-\gamma} \le \pi_1 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi_1)\frac{\tilde{c}_2^{1-\gamma}}{1-\gamma} \Leftrightarrow$$

$$c_2 \le \frac{(1-\pi_2)c_2 + (\pi_2 - \pi_1)c_1}{1-\pi_1} \Leftrightarrow \tag{61}$$

$$c_2 \le c_1$$

where $\tilde{c}_2 = \frac{(1-\pi_2)c_2 + \pi_2 c_1 - \pi_1 c_1}{1-\pi_1} = \frac{(1-\pi_2)c_2 + (\pi_2 - \pi_1)c_1}{1-\pi_1}$.[18]

Since $\rho R \ge 1$ we have from (58) that $c_2 > c_1$. Thus the above expression cannot be satisfied and the incentive compatibility constraint given by (61) is not binding.

The implication of this result is that in our environment, where (unlike Bhattacharya and Gale's model) we choose to

---

[17] This is because, given our utility function specifications, the marginal utility of consumption goes to infinity as consumption becomes zero.

[18] $\tilde{c}_2$ is the sum of $(1-\pi_2)c_2$, what the bank will be left with after giving away the Type II bank's loan return, and $\pi_2 c_1 - \pi_1 c_1$,the excess

respect the sequential service constraint, the inter-bank arrangement is not subject to second-best distortions and is the optimal arrangement, given the constraints imposed by the first-come first-served condition.

Notice that this contract does not involve inefficiencies like the late full and early partial suspension contracts. There is no excess storage in the planning period or premature liquidation of the long-term productive technology. Thus, unless there are exogenously imposed restrictions on the formation of an inter-bank market, lending and borrowing among banks dominates the contracts presented in the previous Sections. Consider the numerical results of the inter-bank contract under the parameters set out in our comparison of the late full and early partial suspension contracts.[19]

Under inter-bank arrangements the contract offered takes the following values: $c_1 = 0.78$, $c_{21} = c_{22} = c_2 = 4.60$. The storage, investment and premature liquidation plan is as follows: $S = 0.59$, $I = 0.41$ and $L = 0$. The ex-ante utility achieved is $U_{IB} = 2.27$, dominating the contracts offered under late full and early partial suspension.

---

wealth in period T=1 that was carried forward using storage, all divided by $(1-\pi_1)$, the remaining proportion of consumers in period T=2.

[19] Let $\phi = 0.7$, $\pi_1 = 0.7$, $\pi_2 = 0.9$, $\gamma = 0.5$, $R = 2.7$, $(1-\tau) = 0.3$ and $\rho = 0.9$.

A note must be made regarding the policy of suspension of convertibility that should complement the inter-bank arrangements. If no premature liquidation of the long-term technology is allowed, the rational of panics is removed, since late consumers' allocations face no threat.

5.6 Discussion

Diamond and Dybvig's attempt to resolve the random withdrawals problem using a policy they termed as deposit insurance came under criticism by Wallace, who demonstrated that it did not respect the sequential service constraint, a condition necessary and central to their exposition.

We make the observation that the same criticism applies to Bhattacharya and Gale's solution to the uncertainty problem over the timing of future consumption needs. Bhattacharya and Gale designed an inter-bank coordination model, but did not take the sequential service constraint seriously in doing so.

In their environment they show that the inter-bank arrangement is subject to second-best distortions that limit the optimality of the contract. In this paper we respect the first-come first-served rule and find that borrowing and lending between banks is the optimal arrangement, subject to the restrictions that the sequential service constraint imposes.

We also ask the question of what alternative options exist if, for reasons exogenous to our environment, an inter-bank coordination mechanism cannot be established. Wallace showed that contracts that form a dependency in the order of withdrawals dominate contracts that do not allow for such contingencies. Nevertheless, he does so in a simplistic environment of no storage or costly liquidation for the productive technology. We alter these conditions to introduce storage possibilities and inefficient premature liquidation of the long-term technology and prove that his results hold even in richer environments.

All the contracts examined assume some form of suspension of convertibility, making them immune to sunspot panics. It could be argued that this result is unrealistic, since banking crises are a feature of the real world. We point out that although suspension of convertibility is effective against sunspot panics, it offers no solution to information-based bank runs. Though the purpose of this Chapter did not involve the study of information-based runs in an environment with aggregate uncertainty about consumption time preference, we identify this as an issue for future research and demonstrate its complexity in Appendix 5.4.[20]

The study of inter-bank arrangements under such a set-up would also highlight the interaction of risk sharing among banks at two levels, liquidity provision and insurance against non-performing portfolios. Koppl and MacGee (2001) take up such a study, but disregard the problem of the sequential service constraint by assuming that the problem of aggregate uncertainty exists only at the planning period and that this uncertainty disappears before any withdrawals or consumption take place.

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[20] In particular, we demonstrate that the introduction of portfolio uncertainty is straightforward for the inter-bank arrangement (and observe that under some environments it becomes subject to second best restrictions) but is more perplex for the late full and early partial suspension cases.

Appendix 5.1

Consider the autarkic solution under this environment of uncertainty over the probability of being an early consumer. The ex-ante expected utility of an agent living under autarky will be:

$$
\begin{aligned}
&MaxU_A = \\
&= \phi\left[\pi_1 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi_1)\frac{c_2^{1-\gamma}}{1-\gamma}\right] + (1-\phi)\left[\pi_2 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi_2)\frac{c_2^{1-\gamma}}{1-\gamma}\right] \qquad (62) \\
&= \left[\phi\pi_1 + (1-\phi)\pi_2\right]\frac{c_1^{1-\gamma}}{1-\gamma} + \rho\left[\phi(1-\pi_1) + (1-\phi)(1-\pi_2)\right]\frac{c_2^{1-\gamma}}{1-\gamma}
\end{aligned}
$$

subject to

$$
\begin{aligned}
c_1 &= 1 - I + (1-\tau)I \\
c_2 &= 1 - I + IR
\end{aligned}
\qquad (63)
$$

With probability $\phi\pi_1 + (1-\phi)\pi_2$ the agent's consumption will be derived from storage and premature liquidation. Ideally, in this case, all would have been left in storage. With probability $\phi(1-\pi_1)+(1-\phi)(1-\pi_2)$ consumption will consist of the return of the productive technology and what was left in storage. Ideally, in this case, all would have been invested in the long-term technology.

Note that the following restriction applies:

$$0 \leq I \leq 1 \tag{64}$$

Investment cannot be negative or higher that the resources available. If $I=0$ or $I=1$ we get the following ex-ante utilities:

$$\begin{aligned} U_{A,I=0} &= [\phi\pi_1 + (1-\phi)\pi_2]\frac{1^{1-\gamma}}{1-\gamma} \\ U_{A,I=1} &= [\phi(1-\pi_1) + (1-\phi)(1-\pi_2)]\frac{R^{1-\gamma}}{1-\gamma} \end{aligned} \tag{65}$$

In terms of the numerical example, given that $\phi=0.7$, $\pi_1=0.7$, $\pi_2=0.9$, $\gamma=0.5$, $R=2.7$, $(1-\tau)=0.3$ and $\rho=0.9$, autarky achieves the low ex-ante utility of $U_A=1.52$, with investment in the productive technology $I=0$.

Appendix 5.2

In Wallace storage is non-existent. There is only one type of technology, where for every unit invested in the planning period it returns R_1 in period T=1 and, if kept until period T=2, it yields R_1R_2.

The program that respects the sequential service constraint but does not make allocations contingent on the order of withdrawals is:

$$MaxU_w = \phi\left[\pi_1 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi_1)\frac{c_{21}^{1-\gamma}}{1-\gamma}\right] + (1-\phi)\left[\pi_2 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi_2)\frac{c_{22}^{1-\gamma}}{1-\gamma}\right]$$

(66)

subject to:

$$\begin{matrix} \pi_1 c_1 = (1-K)R_1 \\ (1-\pi_1)c_{21} = KR_1R_2 \end{matrix} \Rightarrow \frac{\pi_1 c_1}{R_1} + \frac{(1-\pi_1)c_{21}}{R_1R_2} = 1 \qquad (67)$$

and

$$\begin{matrix} \pi_2 c_1 = (1-L)R_1 \\ (1-\pi_2)c_{22} = LR_1R_2 \end{matrix} \Rightarrow \frac{\pi_2 c_1}{R_1} + \frac{(1-\pi_2)c_{22}}{R_1R_2} = 1 \qquad (68)$$

where all the available good is invested in the technology in the planning period and (1-K), (1-L) stand for the quantities withdrawn in period T=1 under π_1 and π_2 early consumers respectively.

If we modify this program to fit our environment with storage and costly premature liquidation, we maximise (66) with respect to:

$$\begin{matrix} \pi_1 c_1 = 1 - I \\ (1-\pi_1)c_{21} = IR \end{matrix} \Rightarrow \pi_1 c_1 + \frac{(1-\pi_1)c_{21}}{R} = 1 \tag{69}$$

$$\begin{matrix} \pi_2 c_1 = 1 - I \\ (1-\pi_2)c_{22} = IR \end{matrix} \Rightarrow \pi_2 c_1 + \frac{(1-\pi_2)c_{22}}{R} = 1 \tag{70}$$

which is of course not possible to achieve, since it requires $\pi_1 c_1 = 1 - I = \pi_2 c_1$.

In our model, since c_1 is the result of a decision made in the planning period T=0 and given the low returns of the long-term technology following liquidation, storage is the optimal supplying source of income for consumption in T=1. But the period T=0 choice of how much to store cannot be made contingent on the period T=1 realization of the proportion of early withdrawals. In the simpler environment of Wallace, c_1 is the result of pulling out in T=1 from the only existing technology, accepting a lower return that dominates storage and not liquidating at fire-sale prices. Unlike our model, in Wallace's environment this withdrawal from the only available technology can be made contingent on the proportion of early withdrawals, since the decision is enforced in period T=1 and not in the planning period (as storage would necessitate).

This has also important implications for the policy he identifies as Partial Suspension of Convertibility. In his model this policy does not involve inefficiencies like carrying forward of goods from period T=1 to T=2 (resulting from excess storage in period T=0) or premature costly liquidation of the long-term technology (to cover shortages in period T=1, the result of under-storage in period T=1).

His policy of Partial Suspension of Convertibility, given that storage is non-existent and there is only one type of technology as described earlier, would involve making period T=1 consumption depend in the order that people withdraw. The expected utility of the contract he describes is:

$$\begin{aligned} U_{WPSC}(\varepsilon) = \phi &\left[\pi_1 \frac{(c_1+\varepsilon)^{1-\gamma}}{1-\gamma} + \rho(1-\pi_1)\frac{c_{21}{}^{1-\gamma}}{1-\gamma} \right] \\ +(1-\phi) &\left[\pi_1 \frac{(c_1+\varepsilon)^{1-\gamma}}{1-\gamma} + (\pi_2-\pi_1)\frac{(c_1-\varepsilon)^{1-\gamma}}{1-\gamma} + \rho(1-\pi_2)\frac{c_{22}{}^{1-\gamma}}{1-\gamma} \right] \end{aligned} \quad (71)$$

subject to:

$$\begin{matrix} \pi_1(c_1+\varepsilon) = (1-K)R_1 \\ (1-\pi_1)c_{21} = KR_1R_2 \end{matrix} \Rightarrow \frac{\pi_1(c_1+\varepsilon)}{R_1} + \frac{(1-\pi_1)c_{21}}{R_1R_2} = 1 \quad (72)$$

and

$$\begin{aligned} &\pi_1(c_1+\varepsilon) + (\pi_2-\pi_1)(c_1-\varepsilon) = (1-L)R_1 \\ &(1-\pi_2)c_{22} = LR_1R_2 \end{aligned} \Rightarrow$$
$$\frac{\pi_1(c_1+\varepsilon)}{R_1} + \frac{(\pi_2-\pi_1)(c_1-\varepsilon)}{R_1} + \frac{(1-\pi_2)c_{22}}{R_1R_2} = 1 \quad (73)$$

If the derivative of (71) with respect to ε evaluated at $\varepsilon=0$ is positive, then the Partial Suspension contract yields higher ex-ante utility than the contract that is non-contingent on the order of withdrawals.

Differentiate (71), after plugging in c_{21} and c_{22} from (72) and (73), with respect to ε and let $\varepsilon=0$:

$$\pi_1 c_1^{-\gamma} - (1-\phi)(\pi_2 - \pi_1)c_1^{-\gamma} - \phi\rho\pi_1 R_2 D_1^{-\gamma} - (1-\phi)\rho\pi_2 R_2 D_2^{-\gamma} \tag{74}$$

where c_1, c_{21} and c_{22} are given by the optimisation of (66) with respect to (67) and (68), and:

$$D_1 = \left[\frac{\left[1-\frac{\pi_1 c_1}{R_1}\right]R_1 R_2}{1-\pi_1}\right], \quad D_2 = \left[\frac{\left[1-\frac{\pi_2 c_1}{R_1}\right]R_1 R_2}{1-\pi_2}\right] \tag{75}$$

Differentiate (66), after plugging in c_{21} and c_{22} from (67) and (68), with respect to c_1:

$$\begin{aligned}&\phi\pi_1 c_1^{-\gamma} - (1-\phi)\pi_2 c_1^{-\gamma} - \phi\rho\pi_1 R_2 D_1^{-\gamma} - (1-\phi)\rho\pi_2 R_2 D_2^{-\gamma} = 0 \Leftrightarrow \\ &-\phi\rho\pi_1 R_2 D_1^{-\gamma} - (1-\phi)\rho\pi_2 R_2 D_2^{-\gamma} = (1-\phi)\pi_2 c_1^{-\gamma} - \phi\pi_1 c_1^{-\gamma}\end{aligned} \tag{76}$$

Substituting from (76) into (74) we get:

$$\pi_1 c_1^{-\gamma} - (1-\phi)(\pi_2 - \pi_1)c_1^{-\gamma} + (1-\phi)\pi_2 c_1^{-\gamma} - \phi\pi_1 c_1^{-\gamma} = 2(1-\phi)\pi_1 c_1^{-\gamma} > 0 \quad (77)$$

This implies that, in the environment examined by Wallace, there are positive ε for which the Partial Suspension Contract yields higher ex-ante utility than the best contract that is non-contingent on the order of withdrawals.

Appendix 5.3

For ease of exposition of this Chapter's results, we consider two interesting contracts that can resolve the aggregate uncertainty problem, but which are nevertheless sub-optimal to the solutions presented in Sections 5.3 and 5.4. The first case considers a contract written for the highest possible number of early withdrawals (π_2), implying the storage of goods from period T=1 to T=2 if the low proportion of early consumers arises. In contrast, the second contract is based on the lowest possible number of early withdrawals (π_1), allowing for the liquidation of the long-term technology if the high proportion of early consumers arises.

Consider a contract based on the highest possible number of early withdrawals. This solution is inefficient in the sense that if the low proportion of early consumers materialises, the contract resorts to unproductive storage to carry forward the excess good of period T=1 for consumption in the last period.

The problem faced by a representative agent in period T=1 is:

$$MaxU_S = \phi\left[\pi_1 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi_1)\frac{c_{2S}^{1-\gamma}}{1-\gamma}\right] + (1-\phi)\left[\pi_2 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi_2)\frac{c_2^{1-\gamma}}{1-\gamma}\right] \tag{78}$$

subject to:

$$\begin{matrix} \pi_2 c_1 = 1 - I \\ (1-\pi_2)c_2 = IR \end{matrix} \Rightarrow \pi_2 c_1 + \frac{(1-\pi_2)c_2}{R} = 1 \Rightarrow c_2 = \frac{(1-\pi_2 c_1)R}{1-\pi_2} \tag{79}$$

and:

$$(1-\pi_1)c_{2S} = IR + \left[(1-I) - \pi_1 c_1\right] \Rightarrow c_{2S} = \frac{(1-\pi_2 c_1)R + (\pi_2 - \pi_1)c_1}{(1-\pi_1)} \tag{80}$$

Note that if there are only π_1 withdrawals in period T=1, the consumption c_{2S} in T=2 will consist of the return of the long term-technology and any leftovers carried forward from period T=1, the result of excess storage in the planning period.

By plugging (79) and (80) in (78) and differentiating with respect to c_1 we get the following first order condition:

$$\begin{aligned}&[\phi\pi_1+(1-\phi)\pi_2]c_1^{-\gamma}-(1-\phi)\rho(\pi_2 R)\left[\frac{(1-\pi_2 c_1)R}{1-\pi_2}\right]\\&+\phi\rho(\pi_2-\pi_1-\pi_2 R)\left[\frac{(1-\pi_2 c_1)R+(\pi_2-\pi_1)c_1}{1-\pi_1}\right]^{-\gamma}=0\end{aligned}\qquad(81)$$

which we can solve to get c_1. Note that c_2 and c_{2S}, as given by (79) and (80), are both functions of c_1.

The Incentive Compatibility Constraints for this contract are:

$$\begin{aligned}&\frac{c_{2S}^{1-\gamma}}{1-\gamma}\geq\frac{c_1^{1-\gamma}}{1-\gamma}\\&\frac{c_2^{1-\gamma}}{1-\gamma}\geq\frac{c_1^{1-\gamma}}{1-\gamma}\end{aligned}\qquad(82)$$

So we must ensure that the expected consumption in period T=2 is preferred by late consumers to withdrawal in period T=1 and storage until consumption in period T=2. If the constraints of (82) are not satisfied, they will have to be included in the maximisation program for the benchmark contract.

The second contract is based on the low proportion π_1 of early withdrawals. It is inefficient in the sense that if the high proportion of early consumers arises, the contract requires the inefficient liquidation of the productive and illiquid long-term technology.

An intermediary chooses consumption bundles to maximise the expected utility of the representative depositor in period T=0:

$$\begin{aligned} MaxU_L = \phi\left[\pi_1 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi_1)\frac{c_2^{1-\gamma}}{1-\gamma}\right] \\ + (1-\phi)\left[\pi_1 \frac{c_1^{1-\gamma}}{1-\gamma} + (\pi_2-\pi_1)\frac{c_L^{1-\gamma}}{1-\gamma} + \rho(1-\pi_2)\frac{c_{2L}^{1-\gamma}}{1-\gamma}\right] \end{aligned} \tag{83}$$

subject to:

$$\begin{matrix} \pi_1 c_1 = 1 - I \\ (1-\pi_1)c_2 = IR \end{matrix} \Rightarrow \pi_1 c_1 + \frac{(1-\pi_1)c_2}{R} = 1 \tag{84}$$

and:

$$\begin{matrix} (\pi_2-\pi_1)c_L = L(1-\tau) \\ (1-\pi_2)c_{2L} = (I-L)R \end{matrix} \Rightarrow \pi_1 c_1 + \frac{(\pi_2-\pi_1)c_L}{(1-\tau)} + \frac{(1-\pi_2)c_{2L}}{R} = 1 \tag{85}$$

where c_L is the consumption allowance resulting from the early liquidation of the long-term technology, distributed to the excess withdrawers of period T=1. This inefficient early liquidation leaves $c_{2L} < c_2$ for consumption by the rest of the consumers in period T=2.

The first order conditions are:

$$\begin{aligned}
&\phi\pi_1 c_1^{-\gamma} + (1-\phi)\pi_1 c_1^{-\gamma} - \lambda\pi_1 - \mu\pi_1 = 0 \Leftrightarrow c_1^{-\gamma} = \lambda + \mu \\
&(1-\phi)(\pi_2 - \pi_1)c_L^{-\gamma} - \mu^{(\pi_2 - \pi_1)}\Big/_{(1-\tau)} = 0 \Leftrightarrow (1-\phi)(1-\tau)c_L^{-\gamma} = \mu \\
&\phi\rho(1-\pi_1)c_2^{-\gamma} - \lambda\frac{(1-\pi_1)}{R} = 0 \Leftrightarrow \lambda = \phi\rho R c_2^{-\gamma} \\
&(1-\phi)\rho(1-\pi_2)c_{2L}^{-\gamma} - \mu\frac{(1-\pi_2)}{R} = 0 \Leftrightarrow \mu = (1-\phi)\rho R c_{2L}^{-\gamma}
\end{aligned} \tag{86}$$

where λ and μ are the Lagrange multipliers associated with the budget constraint given by (84) and (85) respectively.

Combining the second and fourth of the first order conditions of (86) we get:

$$(1-\tau)c_L^{-\gamma} = \rho R c_{2L}^{-\gamma} \Leftrightarrow c_{2L} = \left(\frac{\rho R}{1-\tau}\right)^{1/\gamma} c_L \tag{87}$$

By plugging (87) in (85):

$$\pi_1 c_1 + B c_L = 1 \Leftrightarrow c_L = \frac{1 - \pi_1 c_1}{B} \tag{88}$$

where $B = \frac{\pi_2 - \pi_1}{1-\tau} + \frac{(1-\pi_2)\left(\frac{\rho R}{1-\tau}\right)^{1/\gamma}}{R}$.

From (84) we have:

$$c_2 = \frac{(1-\pi_1 c_1)R}{1-\pi_1} \tag{89}$$

Plug λ and μ from the last two first order conditions of (86) in the first one:

$$\begin{aligned} c_1^{-\gamma} &= \phi\rho R c_2^{-\gamma} + (1-\phi)(1-\tau)c_L^{-\gamma} \Leftrightarrow \\ c_1^{-\gamma} &= \phi\rho R\left(\frac{(1-\pi_1 c_1)R}{1-\pi_1}\right)^{-\gamma} + (1-\phi)(1-\tau)\left(\frac{1-\pi_1 c_1}{B}\right)^{-\gamma} \end{aligned} \tag{90}$$

which we can solve to get c_1. Note that c_2 and c_L given by (89) and (88) are both functions of c_1, and c_{2L} given by (87) is a function of c_L.

The Incentive Compatibility Constraints for this contract are:

$$\begin{aligned} \frac{c_2^{1-\gamma}}{1-\gamma} &\geq \frac{c_1^{1-\gamma}}{1-\gamma} \\ \frac{c_{2L}^{1-\gamma}}{1-\gamma} &\geq \frac{c_1^{1-\gamma}}{1-\gamma} \\ \frac{c_{2L}^{1-\gamma}}{1-\gamma} &\geq \frac{c_L^{1-\gamma}}{1-\gamma} \end{aligned} \tag{91}$$

The first two constraints state that the expected utility from consumption in period T=2 must be preferred by late consumers to withdrawal in T=1 and storage until consumption in T=2. The remaining constraint is needed to ensure that even in the case of inefficient liquidation, there is no scope for late consumers to misrepresent their type and cause a bank run. If the conditions set out in (91) are not satisfied they will have to be included in the maximisation program.

The first contract of this Appendix forbids the premature liquidation of the long-term technology, while the second forbids excess storage in period T=1. The programs described in Sections 5.3 and 5.4 do not impose such restrictions and will thus dominate any contracts that do.

Appendix 5.4

Consider the introduction of a risky portfolio for the inter-bank coordination program. We now revert to the assumptions of the basic model of Chapter 3, where there is a long-term productive technology, whose return is a random variable. At T=0 with probability θ the return in T=2 is low R_l, and with probability $(1-\theta)$ it is high R_h.

The relevant maximisation program is:

$$
\begin{aligned}
MaxU_{IB} &= \phi\left[\pi_1 \frac{c_1^{\,1-\gamma}}{1-\gamma} + \rho(1-\pi_1)A\frac{c_{12}^{\,1-\gamma}}{1-\gamma}\right] \\
&+ (1-\phi)\left[\pi_1 \frac{c_1^{\,1-\gamma}}{1-\gamma} + (\pi_2-\pi_1)\frac{c_L^{\,1-\gamma}}{1-\gamma} + \rho(1-\pi_2)A\frac{c_{22}^{\,1-\gamma}}{1-\gamma}\right]
\end{aligned} \tag{92}
$$

where $A = 1-\theta+\theta\left(\frac{R_l}{R_h}\right)^{1-\gamma}$, subject to:

$$
\begin{aligned}
&\phi\pi_1 c_1 + (1-\phi)\pi_1 c_1 + (1-\phi)(\pi_2-\pi_1)c_L = 1-I \\
&\quad \phi(1-\pi_1)c_{12} + (1-\phi)(1-\pi_2)c_{22} = IR_h
\end{aligned} \Rightarrow
$$

$$
\phi\left[\pi_1 c_1 + \frac{(1-\pi_1)c_{12}}{R_h}\right] + (1-\phi)\left[\pi_1 c_1 + (\pi_2-\pi_1)c_L + \frac{(1-\pi_2)c_{22}}{R_h}\right] = 1 \tag{93}
$$

The first order conditions are:

$$
\begin{aligned}
&\phi\pi_1 c_1^{-\gamma} + (1-\phi)\pi_1 c_1^{-\gamma} - \lambda[\phi\pi_1 + (1-\phi)\pi_1] = 0 \Rightarrow \lambda = c_1^{-\gamma} \\
&(1-\phi)(\pi_2-\pi_1)c_L^{-\gamma} - \lambda(1-\phi)(\pi_2-\pi_1) = 0 \Rightarrow \lambda = c_L^{-\gamma} \\
&\phi\rho(1-\pi_1)Ac_{12}^{-\gamma} - \frac{\lambda\phi(1-\pi_1)}{R_h} = 0 \Rightarrow \lambda = \rho R_h c_{12}^{-\gamma} \\
&(1-\phi)\rho(1-\pi_2)Ac_{22}^{-\gamma} - \frac{\lambda(1-\phi)(1-\pi_2)}{R_h} = 0 \Rightarrow \lambda = \rho R_h c_{22}^{-\gamma}
\end{aligned} \tag{94}
$$

By combining the first two and the last two of the first order conditions we get $c_1 = c_L$ and $c_{12} = c_{22}$. From now on we let $c_{12} = c_{22} = c_2$. Solving we get:

$$c_1 = \frac{1}{[\phi\pi_1 + (1-\phi)\pi_2] + [\phi(1-\pi_1) + (1-\phi)(1-\pi_2)]\frac{(\rho A R_h)^{1/\gamma}}{R_h}} \quad (95)$$

$$c_2 = (\rho A R_h)^{1/\gamma} c_1$$

The expression that needs to be satisfied for a viable contract is:

$$A\frac{c_2^{1-\gamma}}{1-\gamma} \geq \frac{c_1^{1-\gamma}}{1-\gamma} \quad (96)$$

Plugging expression (25) in (24) gives $A(\rho R_h)^{1-\gamma} > 1$ for $\gamma < 1$. Just like in the basic model, this is a sufficient condition for non-binding incentive compatibility constraint.

This assumption occurs naturally as we show in Appendix 3.3. It exists so that we do not impose the long-term technology on risk-averse agents.

The incentive compatibility constraint that relates to Type II banks misrepresenting themselves can be ignored for the reasons we have pointed out in the case without portfolio risk.

The relevant incentive compatibility constraint for Type I banks is:

$$\pi_1 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi_1)\frac{c_2^{1-\gamma}}{1-\gamma} \le \pi_1 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi_1)\left[\theta \frac{\hat{c}_2^{1-\gamma}}{1-\gamma} + (1-\theta)\frac{\hat{\hat{c}}_2^{1-\gamma}}{1-\gamma}\right] \quad (97)$$

where:

$$\hat{c}_2 = \frac{(1-\pi_2)c_2 + (\pi_2-\pi_1)c_1}{(1-\pi_1)}$$
$$\hat{\hat{c}}_2 = \frac{(1-\pi_2)\frac{R_l}{R_h}c_2 + (\pi_2-\pi_1)c_1}{(1-\pi_1)} \quad (98)$$

Consumption in the last period includes a part that depends on the performance of the portfolio and a part that does not. If this constraint is not satisfied it will have to be included in the maximisation program, and then the solution would be subject to additional restrictions and not first-best optimal, unlike the case without portfolio risk.

Let us now turn to late full and early partial suspension under a risky long-term technology. We will only consider the late full suspension case, as our aim is to demonstrate the problems posed by the task of introducing portfolio risk.

The maximisation program under late full suspension in this environment will be:

$$MaxU_{FS} = \phi\left[\pi_1 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi_1)F\frac{c_{21}^{1-\gamma}}{1-\gamma}\right] + (1-\phi)\left[\pi_2 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho(1-\pi_2)G\frac{c_{22}^{1-\gamma}}{1-\gamma}\right] \qquad (99)$$

subject to:

$$\begin{aligned}
&S + I = 1 \\
&\pi_1 c_1 \leq 1 - I \\
&(1-\pi_1)c_{21} = IR_h + (S - \pi_1 c_1) \Rightarrow I = \frac{\pi_1 c_1 + (1-\pi_1)c_{21} - 1}{R_h - 1} \\
&\pi_2 c_1 = S + L(1-\tau) \Rightarrow L = \frac{\pi_2 c_1 + I - 1}{(1-\tau)} \\
&(1-\pi_2)c_{22} = (I - L)R_h \\
&G = 1 - \theta + \theta\left(\frac{R_l}{R_h}\right)^{1-\gamma} \\
&F = 1 - \theta + \theta\left(\frac{IR_l + (S - \pi_1 c_1)}{IR_h + (S - \pi_1 c_1)}\right)^{1-\gamma}
\end{aligned} \qquad (100)$$

By introducing a risky portfolio in the late full suspension model, we observe that the solution to this maximisation is complicated by the inclusion of F, that specifies the consumption allocation to type I banks under the bad and good states of the return of the long-term technology. Although solutions can be found by the use of mathematical software, we judged that this would unnecessarily complicate and would not add significantly to the analysis of this Chapter.

The incentive compatibility constraints to be considered under this contract are:

$$F\frac{c_{21}^{1-\gamma}}{1-\gamma} \geq \frac{c_1^{1-\gamma}}{1-\gamma}$$
$$G\frac{c_{22}^{1-\gamma}}{1-\gamma} \geq \frac{c_1^{1-\gamma}}{1-\gamma} \quad (101)$$

If these constraints are binding they will have to be included in the full suspension maximisation program.

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CHAPTER 6

Twin Crises: Focusing on the Role of Domestic Depositors

6.1 Introduction

The rapidly growing literature on twin crises, that attempts to explain the correlation between banking and currency crises, has emphasized the role of foreign capital flows into the domestic banking system in order to link the two sectors of the economy. Either foreign investors become depositors in domestic banks or domestic banks take up loans from foreign creditors, essentially two sides of the same coin. In this Chapter we describe an alternative explanation for financial crises that focuses on domestic depositors and not on the participation of foreign agents in the domestic economy.

We find that a stable banking sector might come under pressure if the foreign currency market, under a policy of a pegged exchange rate, presents opportunities to domestic depositors for speculation. Furthermore, an unstable banking sector will lead to speculation against a pegged exchange rate regime, which may or may not subsequently collapse.

We also observe that suspending deposit convertibility in the banking sector may decrease the demand for foreign currency in the event of a currency crisis, but will also decrease the welfare of depositors that are unable to obtain their bank savings. If the government cares only about the currency regime and ignores depositors' welfare, suspension of convertibility may be optimal. If the government is sensitive to the events in the banking sector a dilemma may arise regarding the implementation of deposit convertibility suspension.

Our work in this Chapter has also been motivated by the recent events in Argentina (2001). As many economists pointed out, Argentineans at some point in time simply stopped wanting to use the country's currency and preferred to hold dollars fearing possible abandonment of the currency regime. As it was put in an FT article: "Trying to get Argentineans to use the peso is like forcing them to watch black and white television when what they really want is colour".[1] The government in a desperate attempt tried to avoid the collapse of the currency board in place, initially by partially and later on by fully suspending deposit convertibility in the banking sector. This lead to mass marches of

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[1] 'Argentina: Close to anarchy' appearing on the 4th of February, 2002, in the Financial Times.

protesters angered by the loss of their savings and a number of successive governments struggling for order. In our model we try to capture the currency preference reversal by domestic depositors and the reasons backing it, the rationale behind the government's imposed suspension of deposit convertibility and the losses in depositors' welfare that resulted in riots.

Non-financial models of currency crises have been categorised as 'first' and 'second' generation models, following Eichengreen et al (1995). Subsequent of the crisis in East Asia a third generation could be added, although this is a matter of dispute (see Jeanne (1999)).

First generation models were launched by Krugman (1979), followed by a much cleaner paper by Flood and Garber (1984) and extended by a number of other authors. These papers attribute the loss of reserves leading to the collapse of a fixed exchange rate system on the domestic credit expansion related to the monetisation of fiscal deficits. Inevitably investors will launch a speculative attack on the currency, when this falls below a critical level, in their effort to avoid capital losses. Crisis in Mexico in 1976, Argentina, Brazil, Peru and Mexico in 1980's could be attributed to fiscal irresponsibility.

Second generation models are based on Obstfeld (1986). The currency crisis is the result of multiple equilibria and self-fulfilling rational market expectations. A run is based on the logic that the government may choose not to maintain the fixed exchange rate if faced with an attack on the currency peg. In this case the fundamentals must be weak, in order to give signs of conflict in the policy that the rational government may follow. A typical example of such a crisis would be the 1992 sterling crisis, where the investors speculated on the willingness of the UK government to support the fixed rate.

The two generations of currency crises models failed to explain the East Asian crisis, which lead to the design of a number of new theoretical models.[2] Noticeably, a number of authors concentrated on Kaminsky and Reinhart's (1999) observation that balance of payments and banking crises occur simultaneously, in developing third generation models.

Trying to merge the two sectors of the economy, authors extended or combined the Diamond and Dybvig (1983) model of banking crises with first or second generation currency crisis

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[2] Looking at pre-crisis budget balances of the East Asian countries, first generation models are discredited, with minor deficits or even surpluses being the case. Radelet and Sachs (1998) provide further evidence of why in the case of the Asian crisis we cannot rely on a story of the government's misbehaviour generating the crisis. Furthermore, the typical measures of weak macroeconomic indicators in the East Asian countries did not justify such a jump in equilibria as the second generation models would suggest-at least without turning our attention to financial turmoil, with the banking sector contributing to the currency crisis. See Radelet and Sachs.

models.[3] In doing so, they chose one of two ways in achieving their goal.[4]

One type of models concentrates on foreign investors becoming depositors in domestic banks. Representative examples are Goldfajn and Valdés (1997), Diamond and Rajan (2000) and Goldstein (2002). The other type of models involves domestic banks taking up loans from foreign creditors. A number of authors have adapted this view including Chang and Velasco

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[3] Jeanne debates on whether the recent theoretical developments do really form a third generation of models. Instead of the categorization we have been using here (first and second generation models), he supports a different type of terminology. The first generation remains essentially one category, as the Krugman-Flood-Garber intellectual framework. However, following Obstfeld's work, second generation models are given a different definition and the name 'escape clause'. The escape clause approach, according to Jeanne, offers a more holistic view of currency crises, in which each speculator has to figure out how the broad economic conditions, including the expectations of other speculators, influence the policymaker's decisions over the exchange rate. The devaluation is the consequence of the incentives the policymaker is faced with, when considering whether or not to devalue. In this approach, the only condition that a variable must satisfy to qualify as an economic fundamental is to directly or indirectly enter the objective function of the policy maker. So we may extend the set of fundamentals to include 'softer' variables, such as the reputation of the policy maker or the health of the banking system. In this sense, third generation candidates like the models based on the Diamond and Dybvig set-up simply fall under the escape clause category.

[4] Garber and Grilli (1988), in a paper before the Asian crisis studied the possibility of bank runs and contagion in open economies. Nevertheless, they ignored the possibility of currency risk and did not explore the issue of twin crises.

(1998a, 1998b, 2000), Allen and Gale (2000) and Takeda (2001).[5] Of course both types are simply different sides of the same coin: foreign capital flowing into the domestic banking sector.

In this Chapter we follow a different approach to financial crises from the rest of the twin crises models in the literature. We place emphasis on the domestic depositor and ask how his faith on the banking sector's health and the currency peg's viability will affect his actions. We consider a banking sector based on Diamond and Dybvig, with modifications to respect the sequential service constraint (Wallace(1988)) and to include information-based bank runs (Jacklin and Bhattacharya(1988)), a productive technology dependent on fundamentals and illiquidity of investments (Cooper and Ross(1991)). We open up this economy, following Obstfeld, and consider the interactions between the foreign currency and the banking sector in producing twin crises, as well as the results of a policy of suspension of deposit convertibility.

We first present the environment of our model, followed by the banking contract offered under these conditions. We then open up the economy and describe the fixed exchange rate policy

[5] Miller (1998a) studies another interesting case, where a domestic bank run can cause speculative attacks on other currencies, through domestic banks investing abroad and repatriating foreign capital if they face a run. Miller (1998b) explores further the possibility of such cross-border twists.

followed by the government. Next we study financial crises under banking stability and banking instability, followed by the results of a policy of suspension of convertibility in the banking sector. We further qualify and discuss these results, in a separate Section, before we offer our concluding remarks.

6.2 General Framework

We alter the basic model's environment (Chapter 3) by introducing an extra time period, an extra type of consumers, an extra type of investment and a foreign exchange market.

There are four time periods, the planning period T=0 and the consumption periods T=1,2,3. There is a continuum of ex-ante identical agents whose measure is normalised to one and can be one of three distinct types. Type 1 agents prefer consumption in period T=1, type 2 in T=2 and type 3 in T=3. Let π_1, π_2 and π_3 denote the probabilities of being type 1, type 2 and type 3 correspondingly. Their types are revealed to them in period T=1.

In addition to storage, we have two investment opportunities available in the planning period. The first technology is a medium-term risk-less technology that yields $R>1$ units of the good at period T=2 for each unit invested in period T=0. The second technology is a long-term risky technology that yields a random return $\tilde{R}$ at period T=3 for each unit invested at the planning period, where $E(\tilde{R})>R$. At T=0, with probability θ the return in T=2 is low R_l, and with probability $(1-\theta)$ it is high R_h. To capture the irreversibility of the medium and the long-term investments we assume that each unit of liquidation of these technologies in T=1 yields only $(1-\tau)$, where $\tau \in [0,1]$.[6]

Furthermore, we allow for the long-term technology to depend on the state of the economy captured by the state of fundamentals, z, uniformly distributed over the unit interval $z \in [0,1]$. There are two possible states, $S \in (s_1, s_2)$. Under state s_1 the risky technology will yield R_h with certainty. Under state s_2 the return of the risky technology depends on the state of fundamentals. More specifically, there exists a state of fundamentals z^* such that if $z \leq z^*$ then the return of the risky technology will be R_l and if $z > z^*$ then the return will be R_h. Given that the state of fundamentals is uniformly distributed, the above implies:

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[6] This is done in accord to Cooper and Ross. We will need to impose some restrictions on the parameter τ as we progress with the analysis of the model.

$$\begin{aligned} \theta &= prob(S = s_2)z^* \\ 1-\theta &= prob(S = s_1) + prob(S = s_2)(1 - z^*) \end{aligned} \tag{102}$$

where $prob(S = s_1)$ denotes the probability that the state of the economy is s_1 and $prob(S = s_2) = 1 - prob(S = s_1)$ denotes the probability that the state of the economy is s_2.[7]

After agents' types are revealed and before T=1, agents receive a signal about the state of the long-term technology. Before T=2 all agents also learn the state of fundamentals.

Finally, we introduce a foreign exchange market to the domestic economy, by allowing the exchange rate in the absence of government intervention to depend on the state of fundamentals, z. We denote the exchange rate as $f(z)$ and assume that this function is strictly increasing so that a high state of fundamentals corresponds to a "strong currency".

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[7] We assume that the probability that the state of the economy is s_2 is very small. The reason for this assumption is made clear in the following footnote.

6.3 The Banking Contract

Following Diamond and Dybvig, banks will design optimal contracts to provide insurance against agents' liquidity shock.[8] The contracts specify allocations according to the order of withdrawals. Withdrawers in period T=1 receive c_1, withdrawers in period T=2 receive c_2. Following Jacklin and Bhattacharya, the bank pays a promised return c_3 to withdrawers of period T=3 if $\tilde{R} = R_h$ and R_l / R_h of this promised return if $\tilde{R} = R_l$.

The optimisation program yielding these consumption allocations is:

$$MaxU_B = \pi_1 \frac{c_1^{1-\gamma}}{1-\gamma} + \rho\pi_2 \frac{c_2^{1-\gamma}}{1-\gamma} + \rho^2(1-\pi_1-\pi_2)A\frac{c_3^{1-\gamma}}{1-\gamma} \quad (103)$$

[8] We follow Jacklin and Bhattacharya and Alonso (1996), in assuming that that the banking contract cannot be conditioned on the signal S. We also make use of Alonso's result that a contract that makes sure that there will be no misrepresentation by agents even if the interim information is very negative may not be optimal in terms of ex-ante utility. This result can be explained by pointing out that to let an event ($S = s_2$) with very low probability to affect the whole allocation (as we would do in designing a run-proof contract) might be worse in ex-ante utility terms than the contract that allows for runs. Furthermore, we assume that the banking sector designs contracts non-contingent on the expected state of the foreign exchange market.

where $A=(1-\theta)+\theta(\frac{R_l}{R_h})^{1-\gamma}$, subject to:

$$\begin{aligned} \pi_1 c_1 &= 1-M-I \\ \pi_2 c_2 &= RM \\ (1-\pi_1-\pi_2)c_3 &= R_H I \end{aligned} \quad \Rightarrow \pi_1 c_1 + \frac{\pi_2 c_2}{R} + \frac{(1-\pi_1-\pi_2)c_3}{R_H} = 1 \qquad (104)$$

which is the budget constraint of this program and where M signifies investment in the medium-term technology, while I stands for investment in the long-term technology.

The first order conditions are:

$$\begin{aligned} \pi_1 c_1^{-\gamma} - \lambda\pi_1 &= 0 \Rightarrow \lambda = c_1^{-\gamma} \\ \rho\pi_2 c_2^{-\gamma} - \lambda\frac{\pi_2}{R} &= 0 \Rightarrow \lambda = \rho R c_2^{-\gamma} \\ \rho\pi_3 A c_3^{-\gamma} - \lambda\frac{\pi_3}{R_h} &= 0 \Rightarrow \lambda = \rho^2 A R_h c_3^{-\gamma} \end{aligned} \qquad (105)$$

where λ is the Lagrange multiplier associated with the budget constraint.

Solving we get:

$$\begin{aligned} c_1 &= \frac{1}{\pi_1 + \pi_2\frac{(\rho R)^{1/\gamma}}{R} + \pi_3\frac{(\rho^2 A R_h)^{\frac{1}{\gamma}}}{R_h}} \\ c_2 &= (\rho R)^{\frac{1}{\gamma}} c_1 \\ c_3 &= (\rho^2 A R_h)^{\frac{1}{\gamma}} c_1 \end{aligned} \qquad (106)$$

which form the basis for the contract between the bank and the depositors.[9]

We impose the following assumption about the exogenous variables in this model, in the same manner as we did for the basic model of Chapter 3. We assume $A(\rho^2 R_h)^{1-\gamma} > (\rho R)^{1-\gamma} > 1$ for $\gamma < 1$. This ensures that we are not forcing the risk-averse consumers to accept a contract signed on a technology that they would otherwise choose not to invest in. It also implies that we do not need to consider the following incentive compatibility constraints:

$$A\frac{c_3^{1-\gamma}}{1-\gamma} \geq \frac{c_1^{1-\gamma}}{1-\gamma}$$
$$A\frac{c_3^{1-\gamma}}{1-\gamma} \geq \frac{c_2^{1-\gamma}}{1-\gamma} \qquad (107)$$

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[9] We need to impose the following restriction on the parameter τ:

$$(1-\tau) \leq \frac{1}{\pi + (1-\pi)\frac{(\rho A R_h)^{1/\gamma}}{R_h}} = c_1$$

This is necessary in order to ensure that the choice between storage and the long-term technology is not trivial. If the premature liquidation of the investment was to yield more than the bank's promised allocation for period T=1, storage would be completely dominated.

The first constraint states that type 3 agents face no incentive to misrepresent their type and claim the allocation assigned to type 1 agents. The second one regards the incentives of type 3 agents withdrawing in period T=2 as type 2 agents. These results are fully explained in Appendices 6.1 and 6.2.

The incentive compatibility constraint associated with type 2 agents' incentives to withdraw in period T=1 is:

$$\frac{c_2^{\ 1-\gamma}}{1-\gamma} \geq \frac{c_1^{\ 1-\gamma}}{1-\gamma} \tag{108}$$

Since $c_2 = (\rho R)^{\frac{1}{\gamma}} c_1$, $\rho R > 1$ is enough to ensure that it is not binding.

Note that the states $S \in (s_1, s_2)$ associated with the return of the long-term technology, are assigned a new meaning under this banking contract. Under state s_1 the banking sector is stable, since the long-term technology's return will be R_h with certainty. Under state s_2 the banking sector is unstable, since the return of the risky technology depends on the state of fundamentals and information-based bank runs may arise. We gain further intuition on this transition of the long-term technology's property to the banking sector in the following Sections, where we study financial crises.

6.4 Foreign Exchange Market and Government Intervention

The exchange rate in the absence of government intervention depends on the state of fundamentals, z. We now assume that at T=0 the government pegs the interest rate at e^{*}, where $e^{*} \geq f(z)$ for all z. Let V denote the value that the government derives from pegging the exchange rate. The government also faces costs by defending the exchange rate that depend on both the state of fundamentals and the total demand for foreign currency, X.[10] Let $C(X,z)$ denote the cost function which we assume is continuous and is increasing in X and decreasing in z. Then the government's objective is to maximise $V - C(X,z)$.

When at period T=2 all agents learn the state of fundamentals, the government decides whether to keep defending the peg an action that takes place right after period T=2. For simplicity, we assume that the state of fundamentals at period T=1 is such that the government has an incentive to defend the currency. Allowing for the case of weak fundamentals at period T=1 would only introduce some extra cases without yielding any

[10] Later on we show that X depends on the proportion of agents that demand foreign currency.

further insight into the causes of banking and exchange rate crises.

6.5 Financial Crises under Banking Stability

Before T=1 all agents learn the state that signifies whether the returns of the risky technology depend on the fundamentals of the economy. In this Section, we assume that the signal was $S=s_1$, which implies that agents know with certainty that they can withdraw c_3 in period T=3.

When the state of fundamentals is revealed, type 3 agents, whose payoffs depend on the decision of the government whether or not to keep defending the peg, have two options.[11] The first option is not to participate in the foreign exchange market, in which case their consumption allocation in period T=3 will be equal to c_3, since $S=s_1$. The second option involves their participation in the foreign exchange market, where in period T=2 they convert any funds available into foreign currency at the pegged rate e^* and in period T=3 they convert them back into domestic currency (using the single good as the numeraire),

[11] Notice that type 2 agents do not have this option because they only consume in period T=2.

either at the same rate (if the government decides to defend the peg) or at the rate $1/f(z)$ (if the government abandons the peg). In the case of a stable banking system type 3 agents can only participate in the foreign exchange market by pretending to be type 2 agents. If they do so then the bank must liquidate the risky technology and each type 2 and type 3 agent will receive $D_1 = \frac{RM + I(1-\tau)}{1-\pi_1}$. The numerator is equal to the total amount available for distribution, made up of the return of the medium term technology and the liquidation value of the long-term technology, and the denominator is equal to the total mass of type 2 and type 3 agents. Then, when the banking system is stable the second option payoffs are equal to either D_1 (if the government defends the peg) or $D_1 e^* / f(z)$ (if the government abandons the peg).

The total demand for foreign currency, X_{s_1}, is obviously 0 if type 3 agents choose the first option, i.e. they decide not to attack the currency. If they choose the second option and attack the currency $X_{s_1} = \pi_3 D_1$.

The following table shows the payoffs of type 3 agents and of the government conditional on their actions and the state of fundamentals when $S = s_1$.

Table 6.1: Payoffs Under Banking Stability				
	DO NOT ATTACK		ATTACK	
	Government	Type 3 Agents	Government	Type 3 Agents
DEFEND	$V - C(0,z)$	c_3	$V - C(\pi_3 D_1, z)$	D_1
ABANDON	0	c_3	0	$D_1 e^* / f(z)$

In order to make the analysis economically interesting we impose the following restrictions on the payoffs:

1) $c_3 < D_1 e^* / f(0)$; if this is not the case then type 3 depositors would never attack the currency.

2) $C(0,0) > V$; in the worst state of fundamentals even if type 3 depositors do not attack the currency the government's payoff from defending the peg is negative.

3) $C(\pi_3 D_1, 1) > V$; if type 3 depositors attack the currency, then even in the best state of fundamentals the government's payoff from defending the peg is negative.

Denote by $\underline{z}$ the value of z that solves $C(0,z) = 0$; in other words, if $z < \underline{z}$ then the cost of defending the currency exceeds the value even if type 3 depositors do not attack the currency. In addition, denote by $\bar{z}$ the value of z that solves $c_3 < D_1 e^* / f(0)$; in other words, if $z > \bar{z}$ then type 3 depositors cannot benefit by attacking the currency. Then, assuming $\bar{z} > \underline{z}$, we get the following three distinct regions of fundamentals:

(a) if $z < \underline{z}$ the government does not benefit from supporting the peg and type 3 depositors attack the currency with funds obtained by a run at the banking system.

(b) if $\bar{z} > z > \underline{z}$ there are two self-fulfilling equilibria. If there is no demand for foreign currency, then the benefits of defending the currency are higher than the costs and the government maintains the peg, justifying the decision of depositors not to run at the banks and attack the currency. However, if there is high demand for foreign currency, the government will abandon the peg and since $z < \bar{z}$, if depositors expect the currency to be abandoned, they will also expect positive profits, making the decision to force a bank run and attack the currency a rational action.

(c) if $z > \bar{z}$ type 3 depositors do not attack the currency since there are no gains to be made from doing so and the peg is not challenged. Consequently the banking system experiences no runs.

Notice that in case (a) with certainty and in case (b) depending on the expectations of the government and type 3 depositors, an exchange rate crisis leads to a bank run.

6.6 Financial Crises under Banking Instability

In this Section, we assume that the signal $S=s_2$ reveals that with probability z^* the return of the long-term technology will be equal to R_l (and with probability $(1-z^*)$ the return will be R_h) and that the banking system is unstable. The banking system is unstable because with probability z^* the return promised for withdrawals in period T=3 is $\frac{R_l}{R_h}c_3$ (and with probability $(1-z^*)$ the allocation is c_3). In this case, the agents' expected utility from the deposit contract allocation is reduced to $\hat{A}\frac{(c_3)^{1-\gamma}}{1-\gamma}$, where $\hat{A}=(1-z^*)+z^*(\frac{R_l}{R_h})^{1-\gamma}$.

This will result in information-based bank runs, if the following inequality holds:

$$\hat{A}\frac{(c_3)^{1-\gamma}}{1-\gamma}<\frac{(D_2)^{1-\gamma}}{1-\gamma} \qquad (109)$$

where $D_2=\frac{(1-M-I)+(M+I)(1-\tau)}{1}$. We assume that if an information run is about to take place, the bank will liquidate its investments in the two technologies and the liquidation proceeds, together with what was kept in storage, will be distributed to all depositors. If the expected utility from withdrawing in period T=3 is less than the allocation given out following a bank run, type 3 consumers will choose to misrepresent their type.

Note that if R_l is sufficiently low and/or z^* sufficiently high then the deposit contact will cease to be incentive compatible. For simplicity and to facilitate the purpose of this Chapter to study financial crises, we assume that the inequality in (118) holds.[12]

Let us now turn our attention to the foreign exchange market. When the state of fundamentals is revealed type 3 agents have two options just like under banking stability. The first option is not to participate in the foreign exchange market in which case their consumption allocation in period T=3 will be equal to D_2 since in this Section we assume that signal $S = s_2$ reveals an unstable banking system. The second option involves their participation in the foreign exchange market where in period T=2 they convert any funds available into foreign currency at the pegged rate e^* and in period T=3 they convert them back into

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[12] To complete the argument that information-based bank runs will take place in period T=1 if signal $S = s_2$ is received, we also need to show that type 3 agents will not wait until period T=2 and pretend to be type 2 agents, and that type 2 agents will also run at the bank at period T=1 pretending to be type 1 agents. We show under which conditions the run takes place in period T=1 in Appendix 6.3, where we also demonstrate that

domestic currency. The payoffs from the second option will be equal to either D_2 (if the government defends the peg) or $D_2 e^* / f(z)$ (if the government abandons the peg).

Consider the total demand for foreign currency, X_{s_2}. If type 3 agents choose the first option $X_{s_2} = 0$, while if they choose the second option and attack the currency $X_{s_2} = \pi_3 D_2$.

The following table shows the payoffs of type 3 agents and of the government conditional on their actions and the state of fundamentals when $S = s_2$.

Table 6.2: Payoffs Under Banking Instability

	DO NOT ATTACK		ATTACK	
	Government	Type 3 Agents	Government	Type 3 Agents
DEFEND	$V - C(0,z)$	D_2	$V - C(\pi_3 D_2, z)$	D_2
ABANDON	0	D_2	0	$D_2 e^* / f(z)$

The above table suggests that when the banking system is already unstable then attacking the currency becomes a weakly dominant strategy for type 3 depositors. In other words, an unstable banking system leads to betting against the exchange

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the alternative of a bank run in period T=2 does not affect our results in any rate fix, imposed by the government, with certainty. This will lead to the abandonment of the fixed exchange rate depending on the true state of fundamentals and on the total demand for foreign currency.[13]

6.7 Suspension of Convertibility

Consider the implications of a policy that prohibits the premature liquidation of the medium and long-term technologies. The banks follow the following rule: they distribute c_1 to π_1 withdrawers in period T=1 and suspend further payments for that period. In period T=2 they distribute c_2 to π_2 withdrawers, and suspend further payments until period T=3 where they distribute the remaining good to the remaining withdrawers. We term this policy suspension of deposit convertibility.

Suppose that the signal received before period T=1 and relating to the state of the banking sector was $S = s_1$, signifying that the return of the long-term investment is R_h with certainty.

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significant way.

[13] Note that, given our model's assumptions, under banking instability the demand for foreign currency is $\pi_3 D_2$, while under banking

Just like the case without suspension of convertibility, when the state of fundamentals is revealed, type 3 agents have two options. By not participating in the foreign exchange market, they cause no bank run and the demand for foreign currency is $X_{s_1,SoC}=0$. By participating in an attack against the exchange rate peg, they pretend to be type 2 agents, causing a run on the banking system. This time however, the banks are not allowed to liquidate their investments and have to follow the distribution of promised allocations described earlier.

Of the π_2 available c_2 allocations to be distributed in period T=2, $\frac{\pi_2\pi_3}{\pi_2+\pi_3}$ of type 3 agents will receive this allocation. This implies that the demand for foreign currency is $X_{s_1,SoC}=\frac{\pi_2\pi_3}{\pi_2+\pi_3}c_2$.[14] Let us compare this with the demand for foreign currency under no suspension of convertibility. If

stability and an attack on the currency peg the corresponding demand is $\pi_3 D_1$.

[14] $\frac{\pi_2^2}{\pi_2+\pi_3}$ of type 2 agents get c_2, while the remaining $\frac{\pi_2\pi_3}{\pi_2+\pi_3}$ of type 2 agents get nothing. The $\frac{\pi_3^2}{\pi_2+\pi_3}$ of type 3 agents that received nothing in period T=2, withdraw in period T=3 and receive allocation $\bar{c}_3=\frac{IR_h(\pi_2+\pi_3)}{\pi_3^2}$.

$X_{s_1,SoC} < X_{s_1}$, then suspending convertibility will be the government's preferred policy:

$$X_{s_1,SoC} < X_{s_1} \Leftrightarrow 0 < I(1-\tau) \qquad (110)$$

Unless $I=0$ or $\tau=1$, the above inequality holds and the governments preferred action is to suspend deposit convertibility. This policy however leaves some type 2 depositors with zero consumption. Since our government's utility does not incorporate the welfare of depositors, suspension is still the best policy in this environment. We investigate this issue further in the next Section.

Let us now turn to the case where the signal regarding bank stability was $S=s_2$, thus there is instability in the banking sector. In this case the return of the long-term technology is R_l.

All depositors run to withdraw in period T=1. Of the π_3 type 3 depositors, $\pi_1\pi_3$ manage to get c_1 allocation in T=1 before suspension takes place.[15] In period T=2 another $\frac{\pi_2\pi_3(1-\pi_1)}{\pi_2+\pi_3}$ type

[15] Also π_1^2 of type 1 depositors and $\pi_1\pi_2$ of type 2 depositors get c_1 in period T=1. This implies that $\pi_1(1-\pi_1)$ of type 1 depositors have zero consumption.

3 agents get c_2 allocations.[16] The total demand for currency in this case is $X_{s_2,SoC} = \pi_1\pi_3 c_1 + \frac{\pi_2\pi_3(1-\pi_1)}{\pi_2+\pi_3}c_2$.[17] The government will prefer suspension of convertibility if the policy implies lower demand for currency:

$$X_{s_2,SoC} < X_{s_2} \Leftrightarrow RM < I(1-\tau) \qquad (111)$$

So the government will prefer to suspend convertibility if the return of the medium-term technology is low or if the return from liquidation is high (since the liquidation of the medium-term technology could otherwise yield higher amounts available for speculation in the foreign currency market). Note that some type 1 and type 2 depositors will receive nothing for consumption. Once again we point out that we have made the

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[16] Also $\frac{\pi_2^2(1-\pi_1)}{\pi_2+\pi_3}$ of type 2 consumers receive c_2 allocations for consumption. This leaves $\frac{\pi_2\pi_3(1-\pi_1)}{\pi_2+\pi_3}$ type 2 consumers consuming nothing. Note that we have assumed that there is excess demand from both type 2 and type 3 depositors for withdrawal of c_2 allocations in period T=2. Altering this assumption of high proportions of type 2 and type 3 agents would not alter our conclusion in any significant way.

[17] Type 3 depositors that did not manage to withdraw in periods T=1,2 but received $\tilde{c}_3$ in period T=3 are also unable to participate in a run against the exchange rate fix in the foreign currency market.

extreme assumption of a government that does not care about the welfare of depositors and the well being of the banking sector. We explore the consequences of the elimination of this assumption in the following Section.

6.8 Government's Sensitivity to Depositors' Welfare

Consider how our results would change by the inclusion of depositors' welfare in the utility function of the government.

Qualifying the optimality of suspension of convertibility with a government insensitive to the welfare of depositors was straightforward. If the policy results in a lower demand for foreign currency, it is in the interest of the government to impose it. Nevertheless, if we were to alter the government's utility function to depend on the aggregate ex-post utility of the banking sector a policy dilemma may arise.

As we noted in the previous Section, suspension of convertibility will result in lower demand for foreign currency with certainty under banking stability and under certain conditions given banking instability. However, we also noted that the policy resulted in zero consumption for some type 2 agents under banking stability and some type 1 and 2 agents under banking instability. This may considerably lower the aggregate ex-post utility achieved in the banking sector, particularly given the specification of our utility function, where the marginal utility of consumption goes to infinity as consumption becomes zero.

Thus a government that is sensitive to depositors' welfare will be faced with a dilemma. Suspending convertibility will decrease the foreign currency demand and may save the peg, but at the same time it will significantly affect the ex-post utility of the banking sector, which we now assume the government does care about.

We may be tempted to conclude that suspension will be unlikely given zero consumption for a large proportion of agents. But we need to be careful. Our result of zero consumption crucially depends on our choice of corner preferences. If we changed our analysis to include smoother preferences, although bank runs would still result in lower utilities for type 1 and 2 agents, zero consumption would not be possible. Thus the dilemma is non-trivial.

6.9 Discussion

In this Chapter, we studied a model of twin crises independent of foreign agents' interactions. Focusing on the importance of domestic depositors, our aim was to demonstrate the interplay among banking and currency crises and the effect that a policy of suspending deposit convertibility would have in this set-up.

We showed how a stable banking sector can come under threat from weak fundamentals and speculative opportunities in the foreign currency market, as well as how an unstable banking sector can lead to speculative attacks against a fixed exchange rate regime.

Allowing for suspension of convertibility, we demonstrated how a government insensitive to depositors' welfare is likely to suspend deposit payments in the banking sector to prevent the collapse of the currency peg. We also discussed how a government that cares about ex-post utilities in the banking sector will face a dilemma about suspension of deposit convertibility, since suspension decreases the funds available for an attack on the currency regime but also lowers the welfare of domestic depositors. We propose the formal proof of this argument as future research.

Furthermore, we would like to point out the work of Morris and Shin (1988) in identifying a unique equilibrium, unlike the multiple equilibria of Obstfeld, in the foreign currency market by allowing for noise in the signals about fundamentals that speculators receive. Future additions to the model presented in this Chapter could demonstrate the uniqueness of equilibrium, making policy evaluations significantly easier, since currently we cannot attach a priori a probability to each of the multiple equilibria. In that case, we could make specific policy recommendations regarding the use of policies like suspension of deposit convertibility.

Appendix 6.1

The two expressions we need to consider more carefully for a viable contract are:

$$A\frac{c_3^{1-\gamma}}{1-\gamma} \geq \frac{c_1^{1-\gamma}}{1-\gamma}$$
$$A\frac{c_3^{1-\gamma}}{1-\gamma} \geq \frac{c_2^{1-\gamma}}{1-\gamma} \tag{112}$$

From the first order conditions in expression (105) we have that:

$$c_3 = (\rho^2 A R_h)^{1/\gamma} c_1$$
$$c_2 = (\rho R)^{1/\gamma} c_1 \tag{113}$$

Plugging the expressions of (113) in (112) we get $A(\rho^2 R_h)^{1-\gamma} > (\rho R)^{1-\gamma} > 1$ for $\gamma < 1$. This is the assumption used so that the need for including incentive compatibility constraints will not arise. Notice that this assumption occurs naturally as we show in Appendix 6.2.

Appendix 6.2

Let us consider the constraints imposed more carefully. We do this for $\gamma < 1$:

$$A(\rho^2 R_h)^{1-\gamma} > (\rho R)^{1-\gamma} > 1, \text{ where } A = (1-\theta) + \theta(\frac{R_l}{R_h})^{1-\gamma} \quad (114)$$

If we substitute for A:

$$\begin{aligned} &[(1-\theta) + \theta(\frac{R_l}{R_h})^{1-\gamma}](\rho^2 R_h)^{1-\gamma} > (\rho R)^{1-\gamma} > 1 \\ &[(1-\theta)R_h^{1-\gamma} + \theta R_l^{1-\gamma}]\rho^{2(1-\gamma)} > R^{1-\gamma}\rho^{1-\gamma} > 1 \end{aligned} \quad (115)$$

Now also consider when the long-term technology will be preferred to the medium-term technology, which should also be preferred to storage by the risk-averse investors:

$$\begin{aligned} &[(1-\theta)\frac{R_h^{1-\gamma}}{1-\gamma} + \theta\frac{R_l^{1-\gamma}}{1-\gamma}] > \frac{R^{1-\gamma}}{1-\gamma} > \frac{1^{1-\gamma}}{1-\gamma} \Leftrightarrow \\ &[(1-\theta)R_h^{1-\gamma} + \theta R_l^{1-\gamma}] > R^{1-\gamma} > 1 \end{aligned} \quad (116)$$

The expected utility derived from investing in the risky technology must be greater from the utility from the medium-term technology, which must be greater than the utility from storage.

As ρ approaches one, expressions (115) and (116) converge. Thus the assumptions made ensure that the long-term and the medium-term technologies are not forced on the risk-averse consumers by the design of the contract, but they are seen as productive, efficient investments that they would choose to invest in.

Appendix 6.3

To complete the argument that information-based bank runs will take place in period T=1 if signal $S = s_2$ is received, we also need to show that type 3 agents will not wait until period T=2 and pretend to be type 2 agents, and that type 2 agents will also run at the bank at period T=1 pretending to be type 1 agents.

Note that if type 2 agents run in period T=1, type 3 agents will do so as well. Other things equal type 3 agents prefer the type 2 allocation to the type 1 allocation. We now investigate whether type 2 agents prefer the type 1 allocation to the one that they would receive in period T=2 conditional on type 3 agents pretending to be type 2 and the bank liquidating the long-term risky technology. The relevant inequality is:

$$\frac{c_1^{1-\gamma}}{1-\gamma} > \frac{D_1^{1-\gamma}}{1-\gamma} \Leftrightarrow$$

$$\pi_2 + \pi_3 > \pi_2(\rho R)^{\frac{1}{\gamma}} + \pi_3(\rho^2 A R_h)^{\frac{1}{\gamma}} \frac{(1-\tau)}{R_h} \Leftrightarrow \tag{117}$$

$$\frac{\pi_2}{\pi_3} > \frac{(\rho^2 A R_h)^{\frac{1}{\gamma}} \frac{(1-\tau)}{R_h} - 1}{1-(\rho R)^{\frac{1}{\gamma}}}$$

We know from Section 6.3 that $(\rho R)^{\frac{1}{\gamma}} > 1$ and $(\rho^2 A R_h)^{\frac{1}{\gamma}} > 1$. If $(1-\tau)$ is low enough type 2 agents will choose to misrepresent their true type. Alternatively the information-based run will take place in period T=2.

If the run takes place in period T=2, type 3 depositors receive allocation D_1 and the demand for foreign currency is equal to $\pi_3 D_1$. The following table shows the payoffs of type 3 agents and of the government, conditional on their actions and the state of fundamentals, when $S = s_2$ and the run takes place in period T=2.

Table 6.3: Payoffs Under Banking Instability

	DO NOT ATTACK		ATTACK	
	Government	Type 3 Agents	Government	Type 3 Agents
DEFEND	$V - C(0,z)$	D_1	$V - C(\pi_3 D_1, z)$	D_1
ABANDON	0	D_1	0	$D_1 e^* / f(z)$

The above table suggests, just as in the case where the bank run took place in period T=1, that when the banking system is already unstable, attacking the currency becomes a weakly dominant strategy for type 3 depositors. An unstable banking system leads to betting against the exchange rate fix, imposed by the government, with certainty, whether the bank run took place in period T=1 or T=2. This will lead to the abandonment of the fixed exchange rate depending on the true state of fundamentals and on the total demand for foreign currency. The only difference is that with the banking crises taking place in period T=2, the demand for foreign currency is lower, increasing the chances of the peg's survival.

Thus, whether the inequality of (109) is satisfied or not has no significant relevance to the result we wish to highlight in Section 6.6 regarding financial crises, that an unstable banking system will lead to an attack on the currency peg.

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CHAPTER 7

Discussion

Maturity transformation has characterised banking since its early existence. Bankers discovered that they could promise quick convertibility of deposits into currency while keeping a relatively small reserve requirement, with the excess currency being invested in profitable projects. This arrangement crucially depended on a predictable day-by-day withdrawal demand and on the public's confidence on the guarantee of convertibility.

The work of Diamond and Dybvig (1983) highlighted this function of banking and the risks attached to such transformation of liquidity. If depositors fear mass withdrawals for an indefinite reason, redeeming more than what can be readily supplied by the bankers' reserves (that are contingent on a predicted average rate of short-term demands) can lead to self-fulfilling bank failures. Jacklin and Bhattacharya (1988) demonstrated that information on the state of a bank's portfolio can also lead to runs if future profitability is expected to be low, thus offering an alternative explanation to that of panics.

The discussion on the appropriate explanation of banking failures, assuming there is a single one, has moved on to the empirical research field, with information-based bank runs receiving the most support. Nevertheless, until the issue of the causes of problems in the banking sector is resolved, policy makers must weight the consequences of their actions against both possible sources of instability. We provide a simple environment, combining features of the work of Diamond and Dybvig and Jacklin and Bhattacharya, that allows for both sunspot panics and information-based bank runs, unlike the models in the existing literature.

This framework can be used for the study of a number of policies related to the banking sector. We put the policy of suspension of convertibility on the test and observe that a trade off emerges regarding the policy's implementation. As Diamond and Dybvig pointed out, a pre-announced rule of suspension of convertibility can eliminate the rational behind panics. But in the presence of information-based bank runs we show that the decision may not be without dear consequences. The basic model allows for costly premature liquidation of banks' illiquid long-term investments. This feature enables us to demonstrate that it may be optimal to maintain convertibility and allow premature liquidation if such an action performs better than a deteriorating bank portfolio in ex-post welfare terms. Alternatively, if fire-sale prices are too low, suspension may still be preferred.

Furthermore, we expand the basic model to take into account the possibility of contagion, using information as the propagation mechanism in contrast to most of the studies that concentrate on an inter-bank market. We show that the strict rule of suspension of convertibility limits the government's ability to signal to depositors of banks other than the troubled ones that continuation of investments should still be desirable. In a world where banks' portfolios are positively correlated, a single information-based bank failure may spread by panic to the rest of the banking sector. If discretion is followed regarding suspension of convertibility, the observation of the policy's implementation on troubled banks suggests to depositors of the remaining banks in the economy that investments are not performing as bad as observers may have originally deduced, thus averting a systemic panic.

Given these results our policy recommendations strive for rules that allow for all possible states of the economy, thus indirectly supporting transparency in policy related decision making and implementation. A rule that suspends payments in all cases would be too strict, forbidding liquidation when it is the optimal option and restricting the signalling properties of discretion. Discretion on the other hand does not eliminate sunspot panics. But a rule that restricts payments in all cases, except when the banks' portfolio returns are extremely low, combines all the desired properties of the other two extreme possibilities.

Extensions of the basic model can be used to study deposit insurance, inter-bank markets and other possible policies and features of banking. Cross-policy comparisons would then be possible, for example, evaluating the effectiveness and efficiency of suspension of convertibility versus deposit insurance. Furthermore we could apply our structure of information-based contagious panics to study geographical spread patterns based on the portfolio return correlation knowledge among agents in the economy.

Another risk highlighted in the research of Diamond and Dybvig was that of aggregate uncertainty about consumption time preference. In other words, the question arises of what can be done when day-to-day withdrawals are not predictable. Building on the work of Wallace (1988), we show in a richer environment that partial suspension may be welfare improving in comparison to full suspension of convertibility. Nevertheless, if there are no restrictions associated with the creation or the efficient functioning of an inter-bank market, borrowing and lending among banks will be the optimal solution. We demonstrate this by altering the Bhattacharya and Gale (1987) model to respect an important feature of banking, namely the sequential service constraint. This constraint necessitates that depositors' claims are honoured in a first-come first-served basis and respecting it implies that banks participating in an inter-bank arrangement must make common early consumption allocation promises, a rule embedded in our basic model but which has not always been honoured in the literature.

In our study of aggregate uncertainty we abstracted from the possibility of information-based bank runs, because this would have complicated our results extensively without significantly contributing to the aim of the particular exercise. Nevertheless, such an extension would be particularly interesting for exposing the role of asset risk in the workings and possible malfunctions of an inter-bank mechanism.

Our last study opens up the domestic banking sector to a foreign exchange market in an economy with an imposed currency peg. Our aim was to demonstrate the possibility of twin crises and explore the interactions between the two sectors. In contrast to the existing literature that places emphasis on the role of foreign capital in the domestic banking system as an explanation of simultaneous banking and foreign exchange market crises, we focus on the domestic depositor as the main factor of instability. If domestic speculators use domestic bank deposits to take advantage of opportunities in the foreign exchange market, a currency crisis triggers a banking crisis. On the other hand, if a banking crisis takes place because of bad performing bank portfolios, depositors may use withdrawn funds to speculate against the currency peg and the regime may subsequently collapse depending on the strength of fundamentals. In this set-up we examine the role of a policy of suspension of convertibility. A government insensitive to depositors' welfare may prevent a currency crisis by imposing restrictions on the convertibility of deposits into domestic currency, thus decreasing the pool of money available for speculation in the foreign exchange market. However, as a direct consequence of this policy, many depositors are left with little or no consumption at all. Alternatively, a government that weights the survival of the regime against the loss on depositors' welfare will be left with a dilemma regarding suspension of convertibility.

The set-up explored can be particularly useful for studying policy implementation if it is integrated with the work of Morris and Shin (1988). Morris and Shin introduce noisy signals about fundamentals, thus resolving the indeterminacy of equilibria in the foreign exchange market. Given a unique equilibrium, we could attach a probability to each of the current multiple equilibria, thus making policy evaluations significantly easier.

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