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Financial Crisis: A Model Based on Corporate Liquidity

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There is always more to learn.

Abstract

We extend the general analysis on corporate liquidity management of Holmström and Tirole (1998) to include international liquidity, in which financial crises can emerge when domestic agents, in particular firms and banks, experience liquidity shortages. Most efforts to formalize such crises argue that the primary source of instability stems from the function of the banking system as provider of liquidity insurance to households. This dissertation introduces a novel approach to crisis modeling, which emphasizes two aspects overlooked in previous formal models, the role of the banking system in providing liquidity insurance to firms, and that of corporate balance sheets. We show that financially constrained domestic firms can transfer liquidity problems to the banking system, which can signal solvency problems that reduce the incentives for foreign lenders to supply liquidity, since their willingness to lend depends on bank balance sheet robustness.

Keywords: Liquidity, Corporate Liquidity, Balance Sheets, Financial Crises

JEL Classification Codes: F41, G01, G21, G32

Resumo

Estendemos a análise geral da gestão da liquidez empresarial de Holmström e Tirole (1998) de modo a incluir liquidez internacional, no âmbito da qual podem surgir crises financeiras quando os agentes domésticos, em particular as empresas e bancos, enfrentam escassez de liquidez. A maioria dos esforços de formalização destas crises argumenta que a principal fonte de instabilidade decorre da função do sistema bancário enquanto fornecedor de seguro de liquidez às famílias. Esta dissertação introduz uma nova abordagem à modelização de crises, que enfatiza dois aspetos negligenciados nos modelos formais anteriores: o papel do sistema bancário na provisão de seguro de liquidez às empresas e dos balanços das empresas. Mostramos que as empresas domésticas com restrições financeiras podem transferir problemas de liquidez ao sistema bancário, o que pode sinalizar problemas de solvabilidade que reduzem os incentivos dos credores estrangeiros para fornecer liquidez, uma vez que a sua disposição para conceder crédito depende da robustez dos balanços dos bancos.

Palavras-chave: Liquidez, Liquidez Empresarial, Balanços, Crises Financeiras

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1. Introduction

Extensive financial crisis research, most notably Chang and Velasco (2001), emerged from the seminal work of Diamond and Dybvig (1983) on household liquidity risk.[1] Yet, this approach focuses solely on households and omits firm liquidity. As a result, firm demand for liquidity remains virtually unexplored in crisis modeling, even though weaknesses or mismatches (illiquidity) in corporate sector balance sheets are widely recognized as a major cause of severe economic disruptions (e.g., external crises in emerging market economies of the 1990s). Existing crisis models within the Diamond-Dybvig paradigm are unable to capture this features. This suggests that crisis modeling could benefit from assigning an important role to corporate financial structure and liquidity positions.

This dissertation proposes a framework of crashes stemming from illiquidity and balance sheet vulnerability. We argue that liquidity pressures from the non-financial sector can trigger distress in the financial sector through an interaction between balance sheets. Firms in our model, to hedge against potential liquidity shortages, proactively secure bank credit lines on the liability side of their balance sheets. This places responsibility for redeploying resources across the economy on the banking sector. In distress, firms rely heavily on credit lines to avoid illiquidity, which would otherwise leave investment projects unfinished or force their premature liquidation. Large-scale drawdowns can lead to a banking crisis, generating real losses for the banking system as illiquidity morphs into insolvency. At the same time, credit-constrained firms struggle to sustain ongoing operations, driving output contractions through real-sector channels in a self-reinforcing feedback loop.

The model extends the general framework of corporate liquidity management developed by Holmström and Tirole (1998) to an international context, adapting the methodological innovations from Chang and Velasco (2001). This allows us to explore how introducing foreign liquidity to banks in an open economy affects domestic financial fragility and the likelihood of crises. Aggregate liquidity shortages, for instance, may occur spontaneously, reflecting structural features of the economic environment, which could be eliminated through international borrowing. Despite a wide array and depth of international financial instruments, world capital markets cannot always meet liquidity needs. This interaction hinges on the extent to which banks can credibly commit to repaying their foreign debt.

[1] See, for example, Allen and Gale (1998, 2000), Bhattacharya and Gale (1987), Goldstein and Pauzner (2005), and Jacklin and Bhattacharya (1988), among others.

Our main objective is to uncover the implications of aggregate liquidity shortages following bank access to world capital markets. We analyze the ability of the banking sector to perform the task of liquidity supply through credit line contracts across different stochastic structures: (i) idiosyncratic shocks; (ii) perfectly correlated aggregate shocks; and (iii) correlated shocks. As is well established, firm-idiosyncratic shocks result in complete self-sufficiency, since existing liquidity can be pooled and dispatched to support firms in adverse circumstances. In the event of perfectly correlated aggregate shocks, a shortage of liquidity prevents reallocation across states of nature, since excess funds in healthy states are not enough to cushion distressed states. Every foreign creditor refuses to lend, knowing they will not get their money back and anticipating a default. The situation in which the environments are partially correlated shows that the potential lack of self-sufficiency may be compensated by resorting to international borrowing. As long as banks experience temporary illiquidity as opposed to insolvency, emergency funding can be obtained from world capital markets. We conclude that foreign credit is particularly useful when aggregate risk exposure is low.

The remainder of the dissertation proceeds as follows. Section 2 provides a review of the relevant literature. Section 3 establishes the conceptual relationship between household liquidity demand and firm liquidity demand. The basic framework of the model of corporate liquidity that we will use throughout is presented in Section 4. In that section, we also investigate whether the corporate sector can endogenously generate sufficient aggregate liquidity to ensure the proper functioning of the economy, as well as the key role of international liquidity. The final section offers concluding remarks. Formal proofs, along with additional technical details, are provided in the appendices.

2. Literature review

The theoretical literature on liquidity is divided into two branches. From one perspective, Diamond and Dybvig (1983) examine household demand for liquidity and show how coordination failures among depositors generate self-fulfilling bank runs. In that model, financial intermediaries issue demand deposits to perform a maturity transformation function designed to pool risk and enhance social welfare—investing a fraction of liquid deposit proceeds into illiquid assets—but exposing the institution to panic runs from depositors regardless of actual liquidity shocks. In a small open economy modeled *à la* Diamond and Dybvig (1983), Chang and Velasco (2001) study the inter-relationship between banking and currency crises, in which local depositor panics may interact with pessimism from international lenders. They center on international illiquidity to emphasize that international capital flows can exacerbate bank illiquidity and vulnerability, a view suggested by Radelet and Sachs (1998). Although models of bank runs and the associated sequential service constraint provide a compelling story of financial crises, they neglect the financial condition of firms and confine the analysis to households, despite the substantial direct impact of private sector actions on real economic activity.

Our modelling approach follows the second perspective, concerned with firm demand for liquidity. In this tradition, Holmström and Tirole (1998) build a model of moral hazard in which firms need pre-arranged financing as they may encounter liquidity problems. Analogously, intermediaries fund future liquidity needs via credit lines, acting as liquidity pools and insurers, though vulnerable to the threat of liquidity shortages. Our principal theoretical departure from this literature is the introduction of a foreign supply of liquidity—a world capital market—that allows domestic banks to borrow abroad.

Holmström and Tirole (2002, 2011) and Caballero and Krishnamurthy (2001, 2003) consider a model of liquidity management featuring two forms of liquidity (domestic and international), in which firms have access to foreign liquidity subject to international collateral. Their models consider international liquidity as a source of insurance and focus primarily on the role of collateral constraints. In contrast, foreign capital flows are restricted to domestic banks rather than firms, and international insurance cannot be obtained in our model. More broadly, beyond these and other modelling aspects, none of the papers on collateral and insurance mentioned above places banks at the center of crises.

Our work also relates to the large literature of "third-generation" crisis models. While "first-generation" logic explains currency crises through mechanical foreign exchange exhaustion and "second-generation" explanations focus on issues of macroeconomic policy, "third-generation" approaches point to balance sheet vulnerabilities in individual sectors of the economy. Some prominent contributions argue that the core weakness resides in the banking system—examples also include Chang and Velasco (2001). They emphasize international illiquidity—arising from liquidity maturity mismatches—which exposes institutions to self-fulfilling runs and foreign creditor panics, forcing premature asset liquidations that impair bank balance sheets, induce a credit crunch, and curtail productive investment. Alternatively, other models focus on the corporate sector—see Aghion et al. (2001, 2004), Céspedes et al. (2004), Gertler et al. (2007), and Krugman (1999). This body of work argues that substantial corporate exposure to foreign debt can trigger deep contractions in real activity. A tightening of external financing constraints, due to self-fulfilling or fundamental shocks, leads to a real exchange rate depreciation, which inflates the domestic currency burden of foreign-denominated debt, erodes firm balance sheets, and contracts investment and aggregate output. In our case, both balance sheets interact simultaneously to amplify external shocks and increase financial fragility.

3. The demand for liquidity

The liquidity view posits that economic agents demand liquid assets for fundamentally different reasons. Distinct answers have given rise to the workhorse models of liquidity examined here. While Bryant (1980) and Diamond and Dybvig (1983) provide groundwork for household liquidity risk, Holmström and Tirole (1998) shift the focus toward firm liquidity risk. A formal correspondence between these traditions is developed in Appendix B. To trace the argument, time is structured across three dates: dates 0,1 and 2.

3.1. Household liquidity demand

Consider an economy in which agents are ex ante identical. At date 0, each consumer invests their entire initial endowment, allocating it between a short-term liquid asset and a long-term illiquid asset. The liquid asset consists of a storage technology. Each unit of consumption good invested in storage technology produces one equivalent unit available one period later. Investment in the long asset can only take place in the initial date, and yields a superior return per unit at date 2 but nothing if liquidated prematurely at date 1.

Investors will face a liquidity shock either at date 1 or date 2 that requires urgent liquidity for consumption.[2] However, as of date 0, an investor does not know when he will need to consume. At date 1, consumers learn whether they experience a liquidity shock, becoming early consumers (referred to as "impatient") who value consumption only at date 1, or late consumers (referred to as "patient") who value consumption only at date 2. Liquidity shocks may reflect unforeseen emergencies, such as illness or job loss, or even large planned expenditures that remain contingent upon specific opportunities, for instance purchasing a house or a car. Each investor has a probability $1-\pi$ of being impatient and π of being patient. An investor cannot buy direct insurance against liquidity needs because individual outcomes (liquidity shocks) are private information and publicly unobservable, yet aggregate distribution remains deterministic and known with certainty in advance.

Note that investors face a nontrivial investment decision subject to private risk. Long-term investment (which is inherently productive) typically yields higher returns over time, whereas liquid assets (such as idle cash reserves) ensure readily available liquidity but have a lower

[2] Household demand for liquidity formalizes the date 1 event as a preference shock rather than a liquidity shock. Throughout this section, the terminology "liquidity shock" is adopted to facilitate comparison with firm demand for liquidity.

expected rate of return, and therefore entail an opportunity cost. Crucially, uncertainty about future liquidity needs makes holding liquid assets valuable. In the absence of planning, agents self-insure individually, and generally results in overprovision of liquidity.

Financial institutions (banks) possess a comparative advantage regarding liquidity provision. Because there is no aggregate uncertainty, they are able to transform illiquid assets by offering liabilities with a different, smoother pattern of returns over time than the illiquid assets offer. Such liquidity transformation service represents a fundamental role within banking. If the bank offers the more liquid deposits and invests in the illiquid assets, it can create liquidity. Accordingly, banks offer risk-sharing demand deposit contracts that provide insurance against liquidity shocks and maximize depositors' ex ante expected utility.

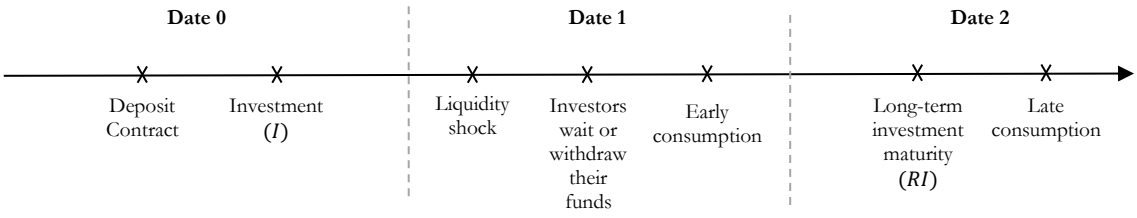


Figure 1: Timeline. Sequence of events in the household liquidity demand model.

Consumers place their endowment with the bank at date 0 to be invested on their behalf. In return, depositors receive promises of fixed consumption at subsequent dates, depending on the timing of their withdrawal decision. The bank acts as a central planner and takes advantage of the law of large numbers to invest in a portfolio where investment in the short-term asset exactly covers average date 1 withdrawals (equal to the proportion of early consumers), with all remaining funds invested in the long-term asset. Centralization of depositors' resources into a collective liquidity pool enables banks to offer insurance contracts with consumption promises contingent on withdrawal dates, delivering a superior combination of liquidity services and investment returns relative to uncoordinated agents.

3.2. Firm liquidity demand

An alternative motivation for liquid asset demand stems from an entrepreneur who wishes only to consume on date 2 but might need to inject some additional funds in order to be able to pursue a project after the initial investment has been sunk. Ongoing projects entail substantial termination (or liquidation) costs if cost overruns are not refinanced. Suppose that at date 1, the entrepreneur faces a liquidity shock with probability $1 - \pi$ ("distressed"

firm), and with probability π ("healthy" firm), experiences no distress and continues. While the most natural interpretation of this liquidity shock is a reinvestment need stemming from an investment cost overrun, it may equally represent a new investment opportunity or a shortfall in earnings at the intermediate stage, both of which require an external cash infusion to cover operating expenses.

Firms seek insurance against the refinancing risk using cash holdings or securing credit lines with a bank.[3] The entrepreneur fully exhausts the credit line if a liquidity shock occurs, but refrains from drawing on it otherwise. Alternatively, firms may hoard reserves in the form of liquid assets to meet the liquidity shock. In this way, firms guarantee funding for financing cost overruns, thereby avoiding the inefficient termination of an ongoing project. It would nevertheless be inefficient for the firm to replace the credit line with holdings of liquid assets, since the opportunity cost of holding liquidity exceeds the cost of the credit line. Also, if it did so, it would be diverting funds from profitable investments.[4]

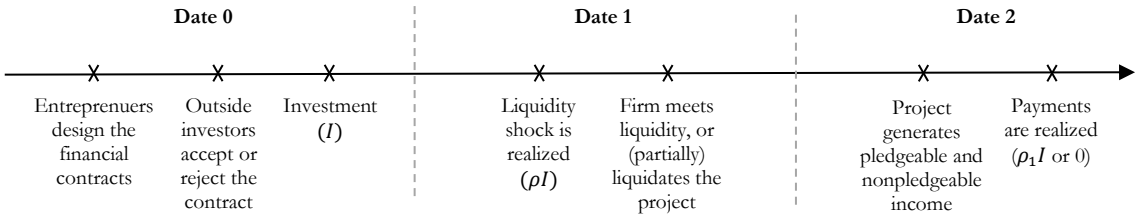


Figure 2: Timeline. Sequence of events in the firm liquidity demand model.

To secure the right to activate a credit line, the entrepreneur pays an upfront commitment fee at date 0, which the bank pools and holds as reserves in liquid assets. At date 1, these accumulated reserves are redeployed to cover liquidity shortfalls within distressed firms. Ultimately, banks allow firms to insure against liquidity shocks through commitments to finance them in the future (via credit lines), while forcing healthy firms to redispatch cash to distressed ones at date 1, thereby preventing the potential waste of liquidity resulting from "self-provision". This liquidity insurance enhances aggregate economic efficiency.

[3] Another option would be to secure access to pools of pledgeable income.

[4] A rich body of empirical and theoretical analyses on the choice and substitutability between cash holdings and credit lines includes, for example, Acharya et al. (2013, 2014), Almeida et al. (2014), Lins et al. (2010), and Sufi (2009).

4. Theory of corporate liquidity

This section extends the canonical model of Holmström and Tirole (1998) to an open economy version and clarifies the role of foreign credit in firm liquidity management.

4.1. The model

The timing of the model is summarized in Figure 3. There are three dates (dates 0, 1, and 2) and a single consumption good. The economy consists of a continuum, with unit mass, of identical entrepreneur-owned firms. Each entrepreneur (also called the "insider"), protected by limited liability, is initially endowed with a net worth (wealth) of $A > 0$ and holds a single investment project with a constant returns to scale technology. To implement the project, which requires a fixed investment I, entrepreneurs may raise capital of $I - A$ from outside investors (the bank) to cover the initial cost, or alternatively, lend their endowment as competitive outside lenders. All agents are risk neutral and the risk-free rate is zero (i.e., investors are willing to lend one unit against a safe return of one unit), with perfect competition among banks ensuring that entrepreneurs appropriate all surplus. Accordingly, the bank provides actuarially fair insurance to break even, so the market rate equals the risk-free rate.

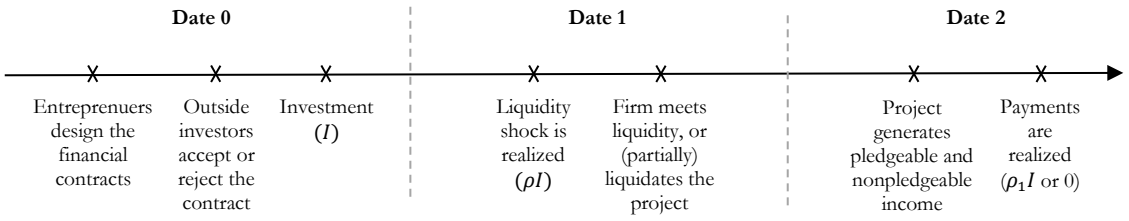


Figure 3: Timeline. The figure depicts the sequence of events in the model.

At date 0 the entrepreneur determines the investment scale $I \in [0, \infty)$ of the project. At date 1 the project experiences a random and publicly observable cost overrun (a "liquidity shock") proportional to the initial investment, which requires an additional investment to ensure its continuation. The liquidity shock per unit of the initial investment ρ is either low ρ_L or high ρ_H with probabilities π and $1 - \pi$ respectively. Continuing at a smaller scale than I is feasible, and the continuation scale is denoted by i with $0 \leq i \leq I$. Conditional on the shock, the project continues at scale $i \in \{i_L, i_H\}$ reflecting the low and high liquidity shock states. The total investment therefore amounts to $I + i_L\rho_L$ or $I + i_H\rho_H$.

Only the portion of the project carried forward yields returns, which are realized at date 2. Specifically, a continuation scale i generates a (public) pledgeable return $\rho_0 i$ that can be credibly committed in advance to pay outsiders, while the entrepreneur appropriates a (private) nonpledgeable return $(\rho_1 - \rho_0)i$. Several mechanisms can justify the wedge between pledgeable and non-pledgeable returns. For instance, firm-specific capital is valuable to the entrepreneur but illiquid for lenders. Similarly, Holmström and Tirole (1997) demonstrate that moral hazard with limited liability naturally generates such a wedge. For simplicity, these specific channels are abstracted from, and the wedge is taken as given. The following features of the project are assumed throughout.

Finance at the start and inefficient ex ante liquidation First, we assume

$$\rho_0 < 1 + \pi\rho_L + (1-\pi)\rho_H < \frac{1+\pi\rho_L}{\pi} < \rho_1. \tag{4.1}$$

Each ratio represents the expected cost of carrying one unit of the project, adjusted by the probability of completing the project. The inequality on the right establishes the social desirability of the project, implying a positive expected net present value (NPV) even if terminated under a high cost overrun, and confirming that continuation across all states is superior to liquidation. Meanwhile, the inequality on the left ensures the project is not self-financing, meaning its pledgeable income ρ_0 is insufficient to cover total investment costs, causing initial credit rationing. Otherwise, a self-financing project could be scaled arbitrarily to generate unbounded payoffs.

Inefficient ex post liquidation Second,

$$0 \leq \rho_L < \rho_0 < \rho_H < \rho_1 \tag{4.2}$$

which means that ex-post continuation is efficient since the initial investment is already sunk cost and $\rho_H < \rho_1$. Furthermore, pre-arranged financing is solely required for shocks above ρ_0, but not for those below ρ_0.

4.2. The second-best contract

A contract between the entrepreneur and outside investors specifies the scale of the project I, the continuation scales $i_L \equiv i(\rho_L)$ and $i_H \equiv i(\rho_H)$ (both $\leq I$), and the final payments for both parties. To maximize the project scale, it is optimal to commit all pledgeable income $\rho_0 i$ to the outside investors, assigning only the illiquid portion $(\rho_1 - \rho_0)i$ to the

entrepreneur. Incentive compatibility leads the entrepreneur to hold only illiquid claims, as the return on internal funds A dominates the risk-free rate. The subsequent results define the second-best.

Lemma The second-best solution solves

$$\max_{\{I,i_L,i_H\}} \pi(\rho_1 - \rho_L)i_L + (1-\pi)(\rho_1 - \rho_H)i_H - I$$

subject to (4.3)

$$\pi(\rho_0 - \rho_L)i_L + (1-\pi)(\rho_0 - \rho_H)i_H \geq I - A$$

$$0 \leq i_L, i_H \leq I.$$

The objective function in the maximization problem represents the expected social return on the investment. The budget constraint, which is the first constraint, binds the bank's outlays to the firm's pledgeable income, making sure that the bank's expected net return covers its initial investment.

The budget constraint shows that the bank provides insurance against liquidity shocks. When the firm experiences a low shock, the bank receives $\rho_0 - \rho_L > 0$. When the firm experiences a high shock, the bank pays the firm $\rho_H - \rho_0 > 0$ per unit of continued investment. Although the project has a negative NPV for the bank in the high-shock state, insurance allows the firm to secure extra funds to continue the project anyway. The solution to the maximization problem is presented below.

Proposition 1 The second-best solution is $\{I, i_L, i_H\} = \{I^*, I^*, I^*\}$ with

$$I^* = \frac{1}{1 - \pi(\rho_0 - \rho_L) - (1-\pi)(\rho_0 - \rho_H)} A. \quad (4.4)$$

Proof Since $\rho_0 - \rho_L$ and $\rho_1 - \rho_L$ are both positive, the bank as well as the entrepreneur prefers full scale continuation when a low shock occurs; hence $i_L = I$. This reduces the program to choosing merely the initial scale I and the continuation scale i_H in the high shock state. Under Assumption (4.1), full continuation is optimal in the high-shock state. At the optimum, the budget constraint binds, so solving for investment I and substituting I in the objective function leads to the result.■

A trade-off between scale and liquidity shapes the optimal design. There are basically two alternatives: the firm can prioritize scale and accept a maturity mismatch—holding mostly

illiquid assets and few short-term assets—or opt for smaller scale, safeguarding its balance sheet. Achieving efficiency means sacrificing scale for complete liquidity insurance, as established by Proposition 1. This result stems from Assumption (4.1), which ensures that continuation is socially desirable across all states of nature, even when the bank generates a negative ex-post NPV.

4.3. Implementation of the second-best contract

To solve the entrepreneur's problem, it is assumed that the firm has no other use for date 1 liquidity besides meeting liquidity shocks, while the bank remains committed to finance projects with a negative NPV. The entrepreneur retains the nonpledgeable income, whereas the pledgeable income is allocated to outside investors. The general equilibrium is then established by the following two results.

Lemma Upon implementation, the entrepreneur solves

$$\max_{\{I,i_L,i_H\}} \pi(\rho_1 - \rho_L)i_L + (1-\pi)(\rho_1 - \rho_H)i_H - A$$

subject to (4.5)

$$\pi(\rho_0 - \rho_L)i_L + (1-\pi)(\rho_0 - \rho_H)i_H \geq I - A$$

$$0 \leq i_L, i_H \leq I.$$

Proof The entrepreneur would rather commit all of the project's pledgeable income to the outside investors so as to make the project scale as large as possible, and keep only the illiquid portion of the income. The entrepreneur only holds illiquid claims because the return on internal funds A exceeds the risk-free rate.■

The budget constraint is binding, and so full continuation is consistently optimal. Accordingly, the subsequent result characterizes the outcome of the entrepreneur's problem.

Proposition 2 Upon implementation, the entrepreneur sets $\{I, i_L, i_H\} = \{I^*, I^*, I^*\}$.

Maximizing expected social return and maximizing the entrepreneur's expected net utility lead to the same solution, which can be reached through several alternative mechanisms. One usual way is to grant the firm a credit line that secures precommitted financing up to $(\rho_H - \rho_0)I$, available for immediate use at date 1. In essence, its option value enables the firm to withstand both kinds of shocks. The firm remains self-financing under a low shock, leaving the credit line unused; but fully exhausts it when a high shock occurs. A credit line

drawdown represents a negative-NPV loan the bank is forced to finance. To compensate for this expected use of liquidity, the bank charges an upfront commitment fee at actuarially fair prices, so it breaks even in expectation.[5]

4.4. Inside liquidity and aggregate shortages

In the previous subsections, we explored the microeconomics behind the difficulties firms encounter in raising funds due to their struggle to convincingly guarantee that investors will recoup their investment, along with the resulting constraints and distortions tied to this credibility issue. From this point forward, the discussion transitions to whether liquidity suppliers—lenders, insurers, and other investors who commit to funding a firm in the future—will actually deliver on that promise when asked to make disbursements at date 1 that carry a negative NPV for them. Although credit line agreements, in particular, are proven to effectively implement the optimal second-best policy, banks may ultimately fail to honor these commitments. The premise is simple: loan commitments are only as credible as the real assets that back them, so it all hinges on whether intermediaries and investors hold enough capital of their own.

As will become clear, limited pledgeability poses a challenge not only to those demanding liquidity but also to those supplying it, imposing a double wedge between outside investors and entrepreneurs that directly restricts the economy's aggregate liquidity, defined as the total pledgeable income accessible to support future liquidity claims. The underlying source of pledgeable income then distinguishes inside (aggregate) liquidity from outside (aggregate) liquidity. Inside liquidity is generated within the corporate sector through financial claims, whereas outside liquidity is provided from beyond the corporate sector.[6]

A pivotal question concerns the conditions under which the corporate sector as a whole is capable of issuing enough inside liquidity to sustain productive activities. Still, even when inside liquidity is sufficient to meet corporate demand, coordination is required—a task credit lines handle through cross-subsidies *à la* Diamond-Dybvig. Whenever inside liquidity is in short supply, a bank operating credit lines faces a liquidity problem, making cross-subsidization (future wealth transfers) no longer feasible.

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[5] Alternatively, the firm can hoard cash reserves at date 0. This requires upfront financing of $I + \rho_H I - A$ from outside investors, who ensure that the firm holds $\rho_H I$ in liquid assets, such as treasury bonds.

[6] For a detailed discussion on the distinction between inside and outside liquidity, see Holmström and Tirole (2011).

This vulnerability gives rise to a second question: to what extent can world capital markets address the bank's potentially illiquid position? Once embedded in an open economy, the bank may inject liquidity into the system from world capital markets, reinforcing inside liquidity to cover the shortage of aggregate liquidity. Such a dynamic rests on the structure of external debt and on the ability of the bank to commit to repay foreign creditors.

To structure the exposition, this subsection proceeds as follows. We first show that when firms face idiosyncratic circumstances, inside liquidity suffices to meet corporate demand. In particular, credit lines are entirely effective, so world capital markets serve no purpose. Next, we examine the scenario in which a common shock hits all firms, creating scope for a shortage of inside liquidity that undermines credit line coordination and renders capital markets inaccessible. Finally, we analyze correlated shocks and the effect of aggregate risk exposure, which also creates a cost to credit lines. In this state of the world, credit lines cannot provide full liquidity insurance across firms in the economy at all times. We delineate circumstances in which credit lines remain feasible, the emerging prominence of world capital markets, and provide a numerical example to illustrate our findings.

4.4.1. Idiosyncratic shocks (independent shocks)

Consider first the extreme case in which liquidity shocks at date 1 are purely idiosyncratic and independent across firms. Given a continuum of ex ante identical agents, the law of large numbers eliminates aggregate uncertainty, rendering aggregate variables deterministic. Suppose for the moment that all firms manage to continue at full scale. Then, the corporate sector as a whole is subject to the following budget constraint

$$\pi(\rho_0 - \rho_L)i_L + (1-\pi)(\rho_0 - \rho_H)i_H \geq I - A > 0,$$

implying that (4.6)

$$(1-\pi)(\rho_0 - \rho_H)I < \pi(\rho_0 - \rho_L)I.$$

On the left side, a measure $1-\pi$ of "distressed" firms (negative NPV) drives liquidity demand, while on the right, a measure π of "healthy" firms (positive NPV) provides liquidity supply.[7] Since shocks are independent, the two shocks are deterministic. We conclude that, as in Holmström and Tirole (2011), with independent shocks, the productive sector is self-

[7] Here, gross inside liquidity is defined as $\pi(\rho_0 - \rho_L)I$.

sufficient with regard to liquidity. Consequently, introducing access to world capital markets would be redundant.

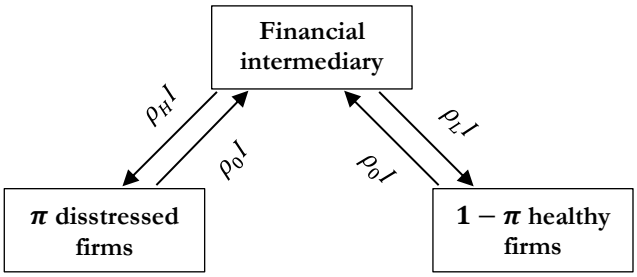


Figure 4: Reallocation process. Cross-subsidization of distressed firms by healthy ones.

In the absence of aggregate risk (shocks are independent), credit lines efficiently manage liquidity through a cross-firm reallocation mechanism. Specifically, because firms facing low shocks do not fully draw down their credit lines at date 1, intermediaries can reallocate the unused liquidity to fully satisfy the higher liquidity demands of firms experiencing high shocks. To this end, firms must, at date 0, pool their liquidity and organize a system of credit lines, paying a commitment fee to the bank to be able to draw enough liquidity in order to continue. The bank then redeploys, at date 1, the accumulated reserves to cover liquidity shortfalls, forcing healthy firms to redispatch cash to distressed ones. As funds are supplied on a contingent basis, firms experiencing a high shock receive $\rho_H I$, whereas those experiencing a low shock get $\rho_L I$.

4.4.2. Perfectly correlated aggregate shocks (large shocks)

At the other extreme, consider that liquidity shocks are perfectly correlated where all firms face either a high $\rho_H > \rho_0$ or a low shock $\rho_L < \rho_0$. A low shock realizes with probability π, while high shocks occur with probability $1-\pi$. It is obvious that a low aggregate shock allows all firms to continue operating. Each firm draws only $\rho_L I$ from its credit line, leaving plenty of excess liquidity unused. By contrast, under a high aggregate shock, the demand for $\rho_H I$ overwhelms the shared pool of liquidity, making continuation impossible for every firm. The fundamental problem is that wealth cannot be moved across states of nature, precluding cross-subsidization from the low-shock state to the high-shock state. As a result, and consistent with Holmström and Tirole (2011), all firms are forced to cease operations in the high-shock state.

At first glance, international borrowing might seem to be the answer for an aggregate shortage of domestic liquidity. This intuition does not hold, however, as credit constraints tighten and the bank loses access to capital markets because its commitment to repay foreign creditors is compromised. Therefore, the argument extends naturally with the incorporation of international capital flows.

4.4.3. Correlated shocks (small shocks)

Assume that some shock exogenous to the corporate sector affects the realized fraction of firms in each state of nature (healthy or distressed) at date 1, which we here normalize to 0. Let ε denote this aggregate risk, where

$$E(\varepsilon|\pi) = 0. \tag{4.7}$$

In practice, ε might represent economy-wide fluctuations rather than firm-specific conditions. Assume that the shock can take values ε and $-\varepsilon$ with equal probabilities; the ex post fraction of firms experiencing low and high liquidity shocks for a given π becomes $\pi + \varepsilon$ and $1 - \pi - \varepsilon$, respectively. Efficient continuation is no longer attainable through a system of credit lines (while it was under idiosyncratic shocks). To illustrate this, suppose a bank, as it would if there were no aggregate risk, uses the law of large numbers since it expects the economy to follow a deterministic path. As a result, the bank is unable to honor credit lines and suffers losses in the case of an adverse shock (i.e., honors credit lines if and only if $\pi \geq \pi^*$), while it honors credit line commitments and realizes gains (it retains unused liquidity) in the case of a favorable one (see Figure 5). For example, the bank has enough liquidity when $\pi = \pi''$ and the shock is favorable and not enough when $\pi = \pi'$ and the shock is adverse. The underlying reasoning is relatively straightforward. When a favorable shock occurs, there are more healthy firms than expected to contribute to fewer distressed firms (the bank wins). Conversely, when an adverse shock occurs, there are fewer healthy firms than expected to contribute to more distressed firms (the bank fails).

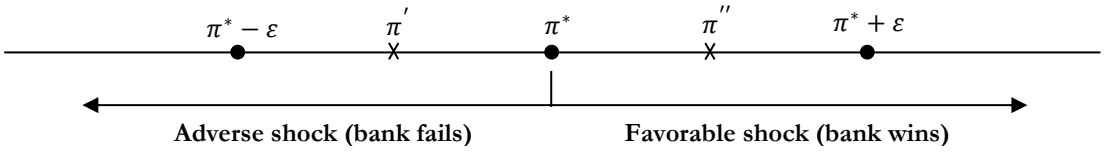


Figure 5: Aggregate risk. The credit line system hinges on state outcomes.

Consider now instead an open economy in which the representative domestic bank has access to a large pool of funds potentially raised in world capital markets where it can invest in a world asset yielding one unit of currency (a "dollar") in either date 1 or date 2 per dollar invested at date 0, and can borrow from abroad up to an exogenous credit ceiling $f > 0$ at a zero interest rate. Market frictions prevent direct corporate debt issuance abroad, as weak investor protection and the need for close borrower monitoring to mitigate asymmetric information position domestic banks at the core of the financial system. All external debt takes the form of short-term, one-period loans, so the bank is unable to obtain insurance in world markets against the exogenous shock.[8]

The bank relies on world capital markets for two purposes, namely the ex ante supply of loans and ex post provision of liquidity. Credit funding at the financing stage (date 0) is contingent on equity capital, possibly combined with external debt.[9] Whenever the bank incurs debt at the initial date, a maturity mismatch follows: bank loans constitute long-term assets, since projects take a while to yield their payoff, whereas the debt that funds them is a short-term liability, maturing before that payoff and ought to be rolled over. Reinvestment needs at the refinancing stage (date 1) could also involve external debt, conditional on the institution's solvency.[10] International creditors evaluate whether the bank has sufficient current and future revenues with which to repay the debt. This spares foreign lenders from collecting information about the bank and project profitability.

Recall that, in a closed economy, if firms are entitled to draw some arbitrary level $\rho_H I$ at date 1, and only a fraction $\pi < \pi^*$ of firms do not exercise that option (adverse shock), pooled funds turn out to be insufficient to honor credit lines. Yet, the domestic bank can now resort to borrow from abroad the resources needed to meet its short-term obligations. Foreign creditors assess the exposure of the bank to the corporate sector and decide whether to accept or refuse to extend new loans.[11] In that sense, equity capital plays the role of a buffer against adverse shocks, and sufficient equity allows the bank to absorb the resulting losses and still honor its future obligations to international creditors, in which case foreign investors

[8] This is an important implicit assumption from Chang and Velasco (2001).
[9] Equity capital ensures that the bank has some "skin in the game". Furthermore, in reality, capital adequacy requirements—established under the Basel Framework—constrain bank lending.
[10] This structure of external debt and reinvestment needs establishes a contrast distinguishing solvency from liquidity. A bank is solvent if the NPV of future net cash flows exceeds total obligations. Nonetheless, it can be illiquid if the funding needed to roll over maturing debt cannot be secured.
[11] Debt incurred by the bank at date 0 is assumed to be automatically renewed, and in the same conditions, whenever foreign creditors agree to extend new loans at date 1.

remain willing to provide lending. Otherwise, once losses exceed the equity buffer, the bank becomes insolvent and loses access to capital markets.

Let us reconsider the credit line mechanism accordingly (see Figure 6). If the shock is adverse and $\pi < \pi^* - \varepsilon^*$, the bank has insufficient liquidity to honor credit lines and foreign creditors are unwilling to provide funding, as losses exceed the bank's equity buffer. On the other hand, if the shock is adverse yet $\pi^* - \varepsilon^* \leq \pi < \pi^*$ (for example, when $\pi = \pi''$), the bank still lacks sufficient liquidity to honor credit lines, but foreign creditors remain willing to provide lending because losses do not surpass the equity buffer. Finally, in the event of a favorable shock $\pi > \pi^*$ (for example, when $\pi = \pi''$), liquidity is sufficient, there is no need for foreign borrowing, and the bank realizes gains.

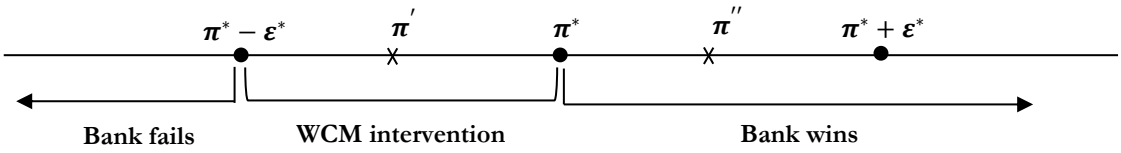


Figure 6: Solvency conditions. The state-contingent foreign supply of liquidity.

In terms of the model, we define the commitment fee paid by the firm to the bank as x, let bank equity capital be represented by K, and normalize the number of firms (population size) to n. Then, for a given set of constant parameters—notably, the number of firms, the firm's initial endowment, pledgeable and non-pledgeable income, the low and high shocks, and bank equity capital—the threshold ε^* above which the bank remains solvent and attractive to foreign creditors is deterministic and defined as

$$\varepsilon^* = 1 - \pi - \frac{xn + K}{nI\rho_H}. \tag{4.8}$$

If $\varepsilon \geq \varepsilon^*$, the bank can absorb the losses generated by ex-post liquidity shocks and still honor its obligations to international creditors. In that case, foreign investors remain willing to provide funding. By contrast, if $\varepsilon > \varepsilon^*$, losses exceed the bank's equity buffer, rendering the institution insolvent and depriving it of access to world capital markets.

After some manipulation, the state-contingent threshold can be rewritten as

$$K + xn = nI\rho_H(1 - \pi - \varepsilon^*), \tag{4.9}$$

to show that solvency is preserved as long as bank capital and the pool of commitment fees are sufficient to cover requested credit lines.

It is of further importance to recognize that international liquidity is concurrently constrained by the economy's limited pledgeability. To secure foreign borrowing, the bank pledges its own balance sheet as collateral to external creditors. Concretely, at maturity, firms reimburse debt to the bank, which is backed by pledgeable income, determining the disposable resources for the bank to meet its obligations to foreign creditors. Therefore, it defines a separate upper bound on foreign debt.

One final point within this rationale demands explicit clarification. Up to this point, we have implicitly assumed that the bank delays borrowing until date 1 to defray potential adverse shocks. An alternative strategy would involve the bank borrowing more resources at date 0—a practice we refer to as precautionary borrowing. Of course, the catch is that if foreign creditors lend heavily at date 0, they become exposed to aggregate risk and cannot adjust their decisions at date 1. Upon an adverse shock that jeopardizes future debt service, external creditors with date-0 exposure prefer to cut losses rather than roll over or extend credit. On top of that, the alternative strategy may not be viable, as foreign lenders might be reluctant to disburse large amounts of capital, particularly considering that a share of those funds is hoarded as reserves at the bank rather than being deployed into investment.

In summary, viewed in this way, world capital markets serve a dual purpose. First, they provide resources, as liquidity-constrained banks channel resources from foreign creditors to firms by issuing bank loans to the corporate sector, which represents the conventional view. Second, they provide liquidity insurance, where the key innovation is that the representative bank's equity acts as an aggregate liquidity buffer. Consequently, the economy can provide liquidity insurance only to the extent that the banking sector holds sufficient net worth to absorb aggregate losses.

4.4.3.1. Numerical example

To fix ideas, consider the following simple numerical example. In a small open economy, there are three dates (dates 0, 1, and 2) and a single consumption good. Agents are risk neutral and do not discount the future.

The corporate sector There is a continuum of ex ante identical firms that own a single long-term project with a constant-returns-to-scale technology and may raise bank capital to

implement the project. At date 0 the entrepreneur chooses the scale of the project $I \in [0, \infty)$, whose returns are obtained at date 2. At date 1 each project is hit by a random liquidity shock proportional to the initial investment, and the entrepreneur must reinvest some extra resources so as to continue with the project. The liquidity shock per unit of the initial investment may be low ρ_L or high ρ_H with probabilities $\pi + \varepsilon$ and $1 - \pi - \varepsilon$ respectively, where ε captures aggregate risk. For expositional simplicity and without loss of generality, the low shock is normalized to $\rho_L = 0$ (meaning no additional capital is required to continue), while the high shock is set at $\rho_H = 1.3$. In this precise case, we will say that the firm is "intact" when it does not need to reinvest and "in distress" when it needs to reinvest $\rho_H = 1.3$ per unit of investment. To be concrete, suppose that $\pi = 0.6$, that $\varepsilon = -0.05$ and that there are $n = 1000$ firms. As a result, 550 firms will face a low liquidity shock and 450 firms will face a high liquidity shock.

Returns on the investment are realized at date 2. The project yields a total present value per unit of investment ρ_1, in which there is a portion of public (pledgeable) return ρ_0 that the entrepreneur can credibly commit in advance to pay the bank. Specifically, assume that $\rho_1 = 1.9$ and $\rho_0 = 1$ (i.e., the project is self-financing).

Each firm has at its disposal $A = \$13$ with which to invest on date 0 and can also buy direct insurance against its need for liquidity through credit lines granted by the bank. As a result, entrepreneurs can draw on their credit lines when needed. The entrepreneur chooses the initial investment scale under the second-best solution, which is given by

$$I^* = \frac{1}{1 - 0.6(1 - 0) - (1 - 0.6)(1 - 1.3)} 13 = \$25,$$

where pledgeable income equals $\$25$ and nonpledgeable income equals $\$47.5$.

There are two alternatives available to the firm. The entrepreneur puts up no equity of its own and borrows from the bank the entire amount of financing needed for the project. That is, any liquidity the entrepreneur has available at the outset is invested in the commitment fee. Alternatively, the entrepreneur can allocate its equity input to the project and borrow $I - A = 25 - 13 = \$12$ from the bank to implement it. At the same time, it uses the

remaining pledgeable income available to purchase the credit line.[12] For the purpose of this illustration, the first option is assumed.

The banking sector The domestic bank is endowed with an equity capital $K = \$10{,}000$ to lend competitively, which is insufficient to finance all projects in the economy. There is a world capital market where one dollar invested at date 0 yields one dollar at either date 1 or date 2. Banks enjoy exclusive access to this world market. The bank can invest as much as it wants, but it can borrow (interest rate is zero) only up to an exogenous credit ceiling of $f > 0$. More precisely, d and b denote net foreign borrowing at dates 0 and 1, respectively, such that $d + b \leq f$. All external debt is short-term consisting of one-period loans. Whether the bank can raise funds abroad depends on its solvency.

The bank initially borrows $d = \$15{,}000$ from foreign creditors to satisfy total financing needs, so that aggregate lending reaches $\$25{,}000$. In turn, since the bank expects a fraction $1 - \pi = 0.4$ of firms to activate their credit lines, the upfront fee is established at $x = \rho_H \times I^* \times (1 - \pi) = 1.3 \times 25 \times 0.4 = \$13$ (paid out of the firm's cash endowment A). The value of the pool of commitment fees, that is, the extent to which the bank can honor its credit line commitments, thus equals $x \times n = \$13 \times 1000 = \$13{,}000$. In exchange, the firm acquires future borrowing privileges, with the bank promising to lend up to $\rho_H \times I^* = 1.3 \times 25 = \$32.5$ to withstand the high liquidity shock.

Information on the exogenous shock ε is revealed to all economic agents. Above prior expectations, 450 firms under distress request to activate their credit lines, requiring an aggregate liquidity injection of $n \times I^* \times \rho_H \times (1 - \pi - \varepsilon) = 1{,}000 \times 25 \times 1.3 \times 0.45 = \$14{,}625$. Given that this amount exceeds the pool of commitment fees, the bank incurs a loss and must borrow an additional $b = \$1{,}625$ from abroad. Ongoing lending takes place and is rational from the perspective of foreign creditors, who face no credit risk as long as the bank remains solvent, but if instead $\varepsilon < 0$ and the resulting loss outstrips bank equity, foreign creditors refuse to extend new loans.[13] Once projects deliver their returns, firm repayments enable the bank to honor its international obligations, resulting in a bank equity capital of $\$10{,}000 - \$1{,}625 = \$8{,}375$.

[12] The bank accepts this form of payment provided that it holds an equivalent amount of its own equity capital to be deployed at the interim date.

[13] The critical threshold for this scenario is $\varepsilon^* = -0.31$.

5. Conclusion

This dissertation embeds access to world capital markets into the standard model of corporate liquidity management. A credit line mechanism follows the intuition behind consumer liquidity demand and arises as a natural instrument to achieve a socially optimal allocation. However, it carries an inherent risk of illiquidity (and the prospect of a systemic crisis), insofar as we demonstrate that aggregate shortages are rooted in the stochastic structure of liquidity shocks. In the presence of purely idiosyncratic uncertainty, there is always enough aggregate liquidity and firms cross-subsidize each other to manage liquidity shocks. At the opposite extreme, with aggregate uncertainty, where all firms face the same (macroeconomic) shock, there is an aggregate liquidity shortage, which world capital markets cannot resolve. In between these two polar cases, with correlated shocks and aggregate risk exposure, where credit lines offer incomplete liquidity insurance, foreign creditors assume a more active role in accommodating shocks within a critical threshold.

Notwithstanding these theoretical insights, it leaves open several promising avenues for future research. A compelling direction would be to examine how the government provision of outside liquidity interacts with international liquidity to alleviate a severe shortage of inside liquidity and provide an implicit form of insurance. On the empirical front, relating this work to concrete historical worldwide episodes, such as the 1990s emerging market crises, could deepen our understanding of financial instability and offer practical lessons for crisis prevention.

Appendix A: Consumer liquidity demand and twin crises

(a) The Diamond-Dybvig model

Liquidity needs arise from timing mismatches between resource availability and expenditure requirements. Households face unpredictable consumption demands while productive investments require extended maturity commitments. Financial intermediaries pool individual risks to provide efficient liquidity allocation, yet remain vulnerable to coordination failures that exhaust available resources when confidence collapses. International capital markets offer an additional source of liquidity through foreign borrowing. Yet, external debt obligations restrict liquidation capacity during crises, as honoring foreign claims absorbs resources otherwise available for domestic depositors.

Consumer liquidity demand and banking fragility receive foundational treatment in Bryant (1980) and Diamond and Dybvig (1983).[14] These contributions abstract from international capital flows and external debt considerations, precluding systematic examination of how foreign borrowing affects financial stability. Incorporating world capital market access subject to credit constraints reveals altered crisis dynamics in Chang and Velasco (2001). Tracing methodological progression across these contributions while maintaining notational consistency establishes how international borrowing intensifies financial vulnerability and propensity for crisis.

Timing. Three periods structure the economy, $t = 0,1,2$.

Consumer preferences. Agents are ex ante identical. Each individual receives endowment $a = 1$ at date 0, investing the entire amount since consumption occurs only at dates 1 or 2. No subsequent endowments arrive. Agents face idiosyncratic uncertainty regarding consumption timing, which clarifies at date 1 with random type realization. Fraction $\pi \in (0, 1)$ discovers they are patient, deriving utility $u(C_2)$ exclusively from date-2 consumption. Remaining fraction $1 - \pi$ discovers they are impatient, deriving utility $u(C_1)$ exclusively from date-1 consumption. Type realizations follow an independent distribution across a continuum population, and the law of large numbers allows for the detection of an exact fraction $1 - \pi$ materializing as impatient, which eliminates aggregate uncertainty while preserving individual

[14] For standard expositions of the Diamond–Dybvig model, refer to Diamond (2007), Freixas and Rochet (2008), and Tirole (2006).

risk. Utility function $u: \mathbb{R}_+ \to \mathbb{R}$ is increasing, strictly concave, twice continuously differentiable, satisfying Inada conditions $\lim_{C\to 0} u'(C) = \infty$ and $\lim_{C\to\infty} u'(C) = 0$. Ex ante expected utility:

$$U = (1-\pi)u(C_1) + \pi u(C_2). \tag{A.1}$$

Technology. Portfolio allocation at date 0 divides endowment between short-term storage and long-term investment. Short-term storage yields gross return 1 per unit invested, deliverable at either date 1 or date 2. Long-term investment delivers return $R > 1$ per unit when maintained through maturity at date 2. Premature liquidation at date 1 yields reduced return r per unit, where $r \leq 1 < R$. Inequality $r < R$ captures fundamental illiquidity, as superior returns require commitment to full maturity, while early termination sacrifices productive value. Long-term projects—infrastructure, industrial capacity, relationship-specific investments—cannot be costlessly redeployed, as premature liquidation destroys project-specific value.

Autarky. Absent coordination mechanisms, each agent independently selects long-term investment I at date 0, holding $(1-I)$ in short-term storage. Upon observing type realization at date 1, an impatient agent liquidates all long-term holdings to consume

$$C_1 = rI + (1-I) = 1 - (1-r)I. \tag{A.2}$$

A patient agent maintains all long-term investment through maturity, consuming

$$C_2 = RI + (1-I) = 1 + (R-1)I. \tag{A.3}$$

Each agent maximizes $(1-\pi)u(C_1) + \pi u(C_2)$ by choice of I. Decentralized decision-making generates ex post inefficiency. Conditional on impatient realization, optimal choice is $I = 0$ (full storage), whereas conditional on patient realization, optimality requires $I = 1$ (full long-term investment). Any interior $I \in (0,1)$ proves suboptimal with positive probability. Consumers face idiosyncratic risk individually despite aggregate outcomes being deterministic, since exactly a fraction $1-\pi$ requires early consumption with certainty. Absence of coordination prevents exploiting this aggregate predictability. Impatient agents wastefully hold illiquid investments requiring costly liquidation, while patient agents wastefully hold liquid storage sacrificing superior long-term returns. *Pooling* through financial intermediation eliminates this cross-purpose allocation.

Social planning problem. A planner observing realized types maximizes representative utility

$$\max_{C_1, C_2, I} (1-\pi)u(C_1) + \pi u(C_2) \tag{A.4}$$

subject to feasibility constraints across types

$$\pi C_1 \leq 1 - I, \tag{A.5}$$

$$(1-\pi)C_2 \leq RI, \tag{A.6}$$

$$C_1, C_2, I \geq 0. \tag{A.7}$$

Constraint (A.5) requires total consumption by impatient individuals not to exceed short-term investment proceeds. Specifically, a fraction $1-\pi$ of agents each consuming C_1 demands $(1-\pi)C_1$ units, supplied by storage investment $1-I$ yielding a unit return. Constraint (A.6) requires total consumption by patient individuals not to exceed long-term investment proceeds. Correspondingly, a fraction π each consuming C_2 demands πC_2 units, supplied by long-term investment I yielding return R.

Since liquidation incurs losses $(r < R)$, it is optimal to avoid premature liquidation. Both feasibility constraints bind at the optimum

$$(1-\pi)C_1^* = 1 - I^*, \tag{A.8}$$

$$\pi C_2^* = RI^*. \tag{A.9}$$

Combining (A.8)–(A.9) yields consolidated resource constraint

$$(1-\pi)C_1 = \frac{\pi C_2}{R} = 1. \tag{A.10}$$

Each unit of impatient consumption costs 1 in date-0 resources (short-term investment at unit cost), while each unit of patient consumption costs $1/R$ in date-0 resources (long-term investment yielding R exploits superior returns). Productivity condition $R > 1$ implies financing patient consumption is cheaper per unit.

Constructing the Lagrangian and deriving first-order conditions yields optimal consumption satisfying

$$\frac{u'(C_1^*)}{u'(C_2^*)} = R. \tag{A.11}$$

Condition (A.11) equates the marginal rate of substitution between consumption levels to marginal rate of technological transformation R. Since $R > 1$ and strict concavity of u

implies u' is decreasing, (A.11) necessarily yields $C_1^* < C_2^*$, meaning that patient individuals receive more consumption, reflecting superior returns from waiting. When $u'(1) > Ru'(R)$, optimal policy additionally satisfies $C_1^* > 1$, with impatient consumers receiving consumption exceeding storage proceeds, embodying insurance transfer from patient to impatient types.

Implementation through financial intermediation. Financial intermediation implements efficient risk sharing by pooling resources. An intermediary collects deposits totaling one unit, invests $I^* = (1-\pi)C_2^*/R$ in long-term projects from (A.9), and holds remaining $1 - I^* = \pi C_1^*$ from (A.8) in storage. Depositors receive contracts specifying withdrawal rights, C_1^* if withdrawing at date 1, or C_2^* if withdrawing at date 2. Withdrawals are serviced sequentially on first-come-first-served basis until resource exhaustion.

Coordination through pooling exploits aggregate certainty despite individual uncertainty. Since exactly fraction $1-\pi$ materializes as impatient, directing all short-term proceeds $1 - I^*$ to these π agents and all long-term proceeds RI^* to remaining π patient agents eliminates autarky's misallocation. Each type receives resources from the technology best suited to their realized preferences, achieving Pareto dominance over autarky through eliminating costly liquidation and providing superior risk sharing. Pooling enables consumption smoothing unattainable under decentralized arrangements. Impatient types access greater resources than individual storage permits, while patient types benefit from efficient long-term investment allocation.

Equilibrium multiplicity. Deposit contracts create demandable liabilities, enabling withdrawal at date 1 regardless of true type, since it is private information. Multiple equilibria emerge.

In the *good equilibrium*, depositors truthfully reveal types. Impatient consumers withdraw C_1^* at date 1 and patient consumers wait for C_2^* at date 2. Since exactly fraction π withdraws early, total withdrawals $\pi C_1^* = 1 - I^*$ precisely exhaust liquid reserves without requiring liquidation. Long-term investment matures to yield $RI^* = (1-\pi)C_2^*$, exactly matching obligations due at date 2. Since $C_2^* > C_1^*$ by (A.11), patient consumers strictly prefer waiting. Truth-telling constitutes Nash equilibrium and, moreover, a dominant strategy equilibrium, with patient consumers preferring to wait regardless of others' actions.

In the *bank run equilibrium*, all agents attempt withdrawal at date 1. Under sequential service, the bank pays C_1^* to depositors in order of arrival until exhaustion. Total resources available

equal liquid reserves plus maximum liquidation proceeds $(1 - I^*) + rI^* = 1 - (1 - r)I^*$. Since $C_1^* > 1$ (insurance provision requires cross-subsidy) and $r < 1$ (liquidation incurs loss), combined with $I^* > 0$ (long-term investment is productive), total available resources fall strictly short of universal promised payments $1 - (1 - r)I^* < C_1^*$. Sequential service exhausts resources after serving only fraction $(1 - (1 - r)I^*)/C_1^* < 1$ of depositors. Even patient consumers rationally withdraw early because waiting guarantees zero consumption since resources will be depleted, whereas early withdrawal offers positive probability of receiving C_1^* before exhaustion. Universal withdrawal is individually rational, constituting Nash equilibrium and confirming self-fulfilling panic.

Multiple equilibria arise from maturity transformation combined with sequential service. Promising $C_1^* > 1$ creates short-term liabilities partially backed by illiquid long-term assets. This structure enables Pareto-superior risk sharing when depositor confidence prevails (good equilibrium) but allows for coordination failure when confidence collapses (bad equilibrium). Banking fragility arises endogenously from liquidity provision.

(b) Open economy extension

Emerging markets routinely access foreign credit to augment domestic savings, financing investment beyond internal resources. However, sovereign risk, informational asymmetries, and capital controls limit borrowing capacity. To understand how constrained access to external credit affects financial vulnerability, one must extend the baseline framework to open economy settings.When borrowing capacity is limited, optimal arrangements may create distinct fragility, in that banking systems cannot mobilize sufficient resources to meet universal withdrawals even when liquidating all domestic assets, because honoring external debt obligations to avoid default reduces resources available for depositors. This dimension, absent in closed economies, fundamentally alters crisis dynamics.

To facilitate transition to Chang and Velasco (2001), this section presents an intermediate specification combining Diamond-Dybvig structure with access to international borrowing. Construction is pedagogical; the complete specification appears in part (c).

Timing. Three-period structure $t = 0, 1, 2$ is preserved.

Consumer preferences. Population structure, type uncertainty characterized by $(\pi, 1 - \pi)$, and utility remain identical to part (a). Expected utility:

$$U = (1-\pi)u(C_1) + \pi u(C_2). \tag{A.12}$$

Technology. Domestic long-term investment yields $R > 1$ at maturity, $r \leq 1$ under liquidation, preserving fundamental illiquidity $r < R$ from part (a). Three new elements are introduced. First, world capital markets offer storage at zero net interest rate, meaning one unit invested at date 0 yields one unit at either date 1 or date 2, with domestic agents free to invest unlimited amounts internationally. Second, domestic agents face borrowing limitations such that aggregate foreign debt cannot exceed the ceiling $f > 0$. Let d denote foreign borrowing at date 0 and b denote foreign borrowing at date 1, both repayable at date 2. Third, the aggregate credit constraint requires that

$$d + b \leq f. \tag{A.13}$$

These modifications expand feasible consumption, with investment now able to exceed domestic endowment through $I = 1 + d$ replacing closed economy constraint $I \leq 1$, raising wealth from 1 to $w = 1 + (R-1)f/R$ and enabling superior risk sharing. However, external debt obligations restrict resources available during crises as honoring foreign claims at date 2 limits liquidation capacity at date 1 exposing the system to a vulnerability absent in the closed-economy context.

Autarky. Each agent chooses (I, d) subject to $I \leq 1 + d$ and $d \leq f$. Impatient individuals consume $C_1 = 1 + d - (1-r)I$ at date 1 through liquidation plus borrowed funds. Patient individuals consume $C_2 = RI + (1-I) - d$ at date 2, where matured investment and storage proceeds cover debt repayment. Ex post inefficiency persists despite international borrowing. Pooling arrangements again dominate autarky.

Social planning problem. A bank chooses (C_1, C_2, I, d, b) to solve:

$$\max_{C_1, C_2, I, d, b} (1-\pi)u(C_1) + \pi u(C_2), \tag{A.14}$$

subject to

$$I = 1 + d, \tag{A.15}$$

$$\pi C_1 = b, \tag{A.16}$$

$$(1 - \pi)C_2 = RI - b - d, \tag{A.17}$$

$$d \leq f, \tag{A.18}$$

$$d + b \leq f, \tag{A.19}$$

$$C_1, C_2, I \geq 0. \tag{A.20}$$

Constraint (A.15) states investment equals domestic endowment plus initial foreign borrowing. Constraint (A.16) requires total consumption by impatient individuals equal initial borrowing from abroad, presuming zero liquidation in optimum. Constraint (A.17) requires total consumption by patient individuals equal matured investment net of total debt repayment ($b + d$). Constraints (A.18)–(A.19) impose borrowing ceilings.

The use of equality rather than inequality in (A.17) reflects that liquidation is not an explicit choice variable, as the bank implicitly sets $l = 0$ in optimum. Part (c) introduces liquidation explicitly as a control variable, necessitating inequality constraints. The methodological difference is pedagogical, in that this intermediate specification simplifies by assuming the optimal result ($l = 0$), while part (c) demonstrates it formally through optimization.

At optimum, the bank avoids liquidation since $R > 1$ (long-term investment dominates), borrowing carries zero cost (world interest rate equals zero), and liquidation incurs losses $r < 1$. All constraints bind because feasibility conditions are driven by Pareto efficiency and the credit ceiling holds since costless borrowing dominates costly liquidation. Substituting (A.15) into (A.17), using $d^* + b^* = f$ from binding (A.19) so that $d^* = f - b^*$, and substituting $b^* = \pi C_1^*$ from (A.16):

$$\pi C_2^* = R + (R - 1)f - R(1 - \pi)C_1^*. \tag{A.21}$$

Rearranging yields consolidated budget

$$(1 - \pi)C_1^* + \frac{\pi C_2^*}{R} = 1 + \frac{(R - 1)f}{R} \equiv w, \tag{A.22}$$

where w represents wealth, defined as domestic endowment plus the present value of borrowing capacity $(R - 1)f/R$. Optimal consumption satisfies

$$\frac{u'(C_1^*)}{u'(C_2^*)} = R. \tag{A.23}$$

Foreign credit expands feasible consumption from $\{(1-\pi)C_1 + \pi C_2/R \leq 1\}$ to $\{(1-\pi)C_1 + \pi C_2/R \leq w\}$ without altering marginal intertemporal trade-off. Since $w > 1$ when $f > 0$, international borrowing enables strictly higher consumption levels for both types while maintaining optimal balance through condition (A.23).

Implementation and international illiquidity. Financial intermediation implements efficient allocation through pooling deposit contracts promising (C_1^*, C_2^*). Optimal portfolio satisfies $I^* = 1 + d^*$ from (A.15). From binding aggregate credit constraint $d^* + b^* = f$ and optimal date-1 borrowing $b^* = (1-\pi)C_1^*$ from (A.16), initial borrowing equals $d^* = f - (1-\pi)C_1^*$.

In the *good equilibrium*, only type 1 agents withdraw at date 1. The bank borrows $b^* = (1-\pi)C_1^*$ from abroad, financing withdrawals without liquidation. Pooling ensures short-term international borrowing finances all impatient consumption while long-term domestic investment finances all patient consumption. At date 2, matured investment $R(1+d^*)$ covers foreign debt f and patient consumption $\pi C_2^* = R(1+d^*) - f$ from (A.17). Since $C_2^* > C_1^*$ by (A.23), truth-telling constitutes Nash equilibrium.

In the *run equilibrium*, all agents attempt withdrawal. The bank mobilizes liquidity using remaining borrowing capacity $f - d^*$ and liquidation constrained by international obligations. Enough funds must be preserved to repay foreign debt at maturity. Let l denote the quantity of investment liquidated at $t = 1$. The constraint $R(I^* - l) = f$ ensures remaining capital yields exactly f at $t = 2$, implying maximum liquidation $l = (RI^* - f)/R$. This liquidation yields resources $r(RI^* - f)/R$ available at $t = 1$. Combined with borrowing $b^* = f - d^* = \pi C_1^*$, total resources at $t = 1$ equal

$$(1-\pi)C_1^* + r \cdot \frac{R(1+d^*) - f}{R}. \tag{A.24}$$

Since $C_1^* > 1$ (liquidity insurance provision) implies $\pi C_1^* < C_1^*$, and liquidation value diminishes as external borrowing f increases, promised payments C_1^* can exceed mobilizable resources. International illiquidity arises when promised payments exceed mobilizable resources, as an intermediary cannot liquidate beyond the margin consistent with debt

repayment, restricting available funds below universal withdrawal demands. Resources are depleted before serving all depositors under the first-come-first-served protocol. Even patient consumers withdraw early, since waiting guarantees zero, whereas early withdrawal offers positive probability of receiving C_1^*. Universal withdrawal is individually rational, confirming panic.

(c) Twin crises and creditor coordination

Crises in emerging markets during the 1990s featured troubled financial institutions and sudden reversals of short-term international capital flows, with currency crashes accompanying banking system collapses. These patterns suggest that crisis models should assign central roles to financial structure, external debt maturity, and interactions between domestic banking fragility and currency pressures. Chang and Velasco (2001) develop such a framework wherein domestic bank runs interact with foreign creditor panics. Twin crises emerge as different manifestations of a unified mechanism rather than independent phenomena requiring separate explanations.

Building on the intermediate open economy specification, Chang and Velasco (2001) introduce four modifications. First, the endowment $a > 0$ is no longer normalized to unity, allowing the model to capture heterogeneity in domestic resource bases and their interaction with external borrowing capacity. Second, liquidation quantity l enters explicitly as a choice variable rather than being determined residually. Third, the liquidation return r is reinterpreted to incorporate fire-sale discounts. When multiple institutions liquidate simultaneously, asset prices are depressed through externalities, reducing r below normal liquidation values and amplifying financial fragility. Fourth, separating borrowing constraints into $d \leq f$ and $d + b \leq f$ as distinct restrictions allows debt maturity structure to operate as an independent source of financial fragility, over and above the credit ceiling itself.

Timing. Three-period structure $t = 0,1,2$ is maintained.

Consumer preferences. Population structure, type uncertainty $(\pi, 1-\pi)$, and utility remain identical. Expected utility:

$$U = (1-\pi)u(C_1) + \pi u(C_2). \tag{A.25}$$

Technology. Domestic long-term investment yields $R > 1$ at maturity. Liquidation at date 1 yields $r < 1$ per unit, capturing fire-sale costs. Parameter r now incorporates value

destruction from forced asset sales, where simultaneous liquidation by multiple institutions during crises depresses prices through market impact, reducing recovery values below normal liquidation levels. Short-term storage yields 1. World capital markets offer storage at zero net interest with foreign borrowing subject to aggregate ceiling $f > 0$. Let $a > 0$ denote domestic endowment, d denote borrowing at date 0, b denote borrowing at date 1, and l denote quantity liquidated at date 1.

Social planning problem. A bank chooses (C_1, C_2, I, d, b, l) to solve:

$$\max_{C_1, C_2, I, d, b} (1-\pi)u(C_1) + \pi u(C_2), \tag{A.26}$$

subject to

$$I = a + d, \tag{A.27}$$

$$(1-\pi)C_1 = b + rl, \tag{A.28}$$

$$\pi C_2 = R(I-l) - b - d, \tag{A.29}$$

$$d \leq f, \tag{A.30}$$

$$d + b \leq f, \tag{A.31}$$

$$C_1, C_2, I \geq 0. \tag{A.32}$$

Constraint (A.27) states investment cannot exceed endowment plus initial borrowing. Constraint (A.28) requires impatient consumption not exceed date-1 borrowing plus liquidation proceeds (quantity l times return per unit r). Constraint (A.29) requires patient consumption not to exceed returns from unliquidated investment $(I-l)$ net of total debt repayment. Constraints (A.30)–(A.31) impose borrowing ceilings.

At optimum satisfying $R > 1$ and $r < 1$, liquidation is suboptimal ($l^* = 0$). Borrowing dominates liquidation since marginal return from holding investment to maturity (R) exceeds liquidation proceeds (r). With $l^* = 0$, constraints (A.27)–(A.31) reduce to those in the intermediate specification when $a = 1$. Both feasibility conditions bind at the optimum

$$(1-\pi)C_1^* = b^*, \tag{A.33}$$

$$\pi C_1^* = R(a + d^*) - b^* - d^*. \tag{A.34}$$

Aggregate credit ceiling binds, $b^* + d^* = f$, as costless borrowing dominates costly liquidation. Substituting $b^* = (1-\pi)C_1^*$ from (A.33) into (A.34) and using binding credit constraint:

$$(1-\pi)C_1^* + \frac{\pi C_2^*}{R} = a + \frac{(R-1)f}{R}. \tag{A.35}$$

First-order condition equating marginal rates of substitution to intertemporal returns:

$$\frac{u'(C_1^*)}{u'(C_2^*)} = R. \tag{A.36}$$

Since $R > 1$ and u strictly concave, this implies $C_2^* > C_1^*$, so patient consumers prefer waiting to early withdrawal, confirming ex post incentive compatibility.

Four crisis channels. Chang and Velasco (2001) identify four distinct mechanisms through which international illiquidity manifests, each generating unique vulnerability patterns. Fire-sale liquidation (z^+). During universal withdrawal, the bank must liquidate assets while honoring external debt obligations. Maximum liquidation consistent with covering foreign debt f at maturity satisfies $R(I^* - l^+) = f$, yielding

$$l^+ = I^* - \frac{f}{R} = (a + d^*) - \frac{f}{R} = \frac{R(a + d^*) - f}{R}. \tag{A.37}$$

Resources mobilizable equal remaining borrowing capacity b^* plus fire-sale proceeds rl^+. The bank faces runs when promised obligations exceed these mobilizable resources. Chang and Velasco (2001) define international illiquidity measure:

$$z^+ \equiv C_1^* - (b* + rl^+) = \pi C_1^* - r \cdot \frac{R(a + d^*) - f}{R}. \tag{A.38}$$

When $z^+ > 0$, universal withdrawal is individually rational. Sequential service implies only fraction $(b^* + rl^+)/C_1^* < 1$ can be served before resource depletion. Declining r increases z^+, expanding parameter regions where runs are feasible. Fire-sale externalities create feedback. Anticipating severe losses, creditors refuse lending precisely when most needed, intensifying liquidation pressure and validating initial pessimism.

Short-term debt rollover (z^b). Suppose initial borrowing d matures at date 1 rather than date 2. If foreign creditors refuse to rollover, the bank must repay d at date 1 alongside depositor withdrawals. Total obligations equal $C_1^* + d^*$ (all depositors withdraw, not just fraction π), met by liquidating entire investment portfolio yielding $r(a + d^*)$. Chang and Velasco (2001) define short-term debt illiquidity:

$$z^b \equiv C_1^* + d^* - r(a + d^*) = C_1^* - ra - (r - 1)d^*. \tag{A.39}$$

Since $r < 1$, term $(r - 1)d^* < 0$ is negative, whereby positive initial borrowing magnifies vulnerability. Creditor rollover refusal constitutes independent crisis mechanism. Coordination failures among foreign lenders precipitate collapse even when depositor confidence is maintained. When creditors refuse the rollover, forced liquidation validates their initial fears. Conversely, rolling over ensures survival and full repayment. Self-reinforcing coordination failures among creditors arise through maturity mismatch between short-term external liabilities and long-term domestic assets.

Sudden stops (z^a). Distinct from rollover refusal, creditors may refuse to extend new credit at date 1 even when no maturing debt requires immediate repayment. Planned borrowing $b^* = \pi C_1^*$ finances withdrawals without liquidation in optimal allocation. If creditors withhold these funds—a sudden stop in capital flows—obtaining b^* becomes impossible despite bank solvency and profitability. Without new lending, initial borrowing d^* remains long-term (repayable at date 2), but liquidation must generate all date-1 liquidity. Maximum liquidation consistent with honoring long-term debt at maturity:

$$l^a = I^* - \frac{d^*}{R} = (a + d^*) - \frac{d^*}{R}. \tag{A.40}$$

Liquidation proceeds equal $rl^a = r(a + d^*) - rd^*/R$. Chang and Velasco (2001) define no-ongoing-lending illiquidity:

$$z^a \equiv C_1^* - rl^a = C_1^* - r(a + d^*) + \frac{rd^*}{R}. \tag{A.41}$$

Since $0 < r < 1 < R$ implies $rd^*/R < d^*$, term rd^*/R only partially offsets negative $-r(a + d^*)$. Parameters may satisfy $z^+ < 0$ (bank survives with ongoing lending) yet $z^a > 0$ (vulnerable without lending). Sudden stops precipitate crises even when banking system would remain solvent with continued credit access. Self-fulfilling creditor panics emerge

independently of depositor behavior, creating multiple vulnerability layers. Vulnerability ordering. Chang and Velasco (2001) establish systematic ordering:

$$z^+ < z^a < z^b. \tag{A.42}$$

Inequality $z^+ < z^a$ reflects that ongoing lending provides liquidity without requiring immediate debt repayment. Direct calculation:

$$z^a - z^+ = \left[C_1^* - r(a + d^*) + \frac{rd^*}{R}\right] - \left[\pi C_1^* - r \cdot \frac{R(a + d*) - f}{R}\right]$$

$$= (1 - \pi)C_1^* + \frac{rd^*}{R} - \frac{rf}{R} = (1 - \pi)C_1^* - \frac{r(f - d^*)}{R}.$$

Since $(1 - \pi)C_1^* = b^* = f - d^*$ from (A.33) and binding credit constraint:

$$z^a - z^+ = (f - d^*)(1 - \frac{r}{R}) > 0$$

where inequality holds since $f > d^*$ (from $b^* > 0$) and $r < R$. Inequality $z^a < z^b$ follows from

$$z^b - z^a = [C_1^* - ra - (r - 1)d^*] - \left[C_1^* - \frac{r(a + d^*)rd^*}{R}\right]$$

$$= r(a + d^*) - ra - (r - 1)d^* - rd^*/R = (2 - r)d^* - rd^*/R > 0,$$

since $(2 - r) > 1$ when $r < 1$ and first term dominates. Short-term debt adds full debt stock d^* to immediate obligations while only partially reducing required liquidation. Parameters may satisfy $z^+ < 0$ (no runs with ongoing lending and long-term debt) yet $z^b > 0$ (runs with short-term debt), demonstrating that maturity structure alone can trigger crises independently of depositor behavior or liquidity provision quality.

Twin crises under fixed exchange rates. Embedding banking within monetary frameworks featuring fixed exchange rates constitutes the most distinctive Chang-Velasco contribution. Central banks commit to converting domestic currency into foreign reserves at fixed rates. When banking crises occur ($z^+ > 0$), central banks may inject domestic currency as lender of last resort preventing failures. However, under fixed exchange rates, currency creation threatens pegs through the following mechanism. Depositors withdraw domestic currency from banks, subsequently presenting currency to central banks demanding conversion into foreign reserves at fixed rates. If initial reserve holdings are insufficient to satisfy conversion

demands, central banks cannot maintain fixed rates. Peg abandonment and currency depreciation follow.

Direct transmission from banking crisis to currency crisis operates through this lender-of-last-resort channel. Identical condition $z^+ > 0$ creating depositor run exposure also generates currency attack exposure when central banks intervene supporting banking systems. Twin crises emerge as simultaneous manifestations of identical underlying international illiquidity conditions, expressed through different channels depending on central bank policy responses. This contrasts sharply with traditional models treating banking and currency crises as independent phenomena requiring separate explanations.

Creditor panics compound currency vulnerability through two channels. First, creditor lending refusals intensify banking crises, increasing intervention pressure threatening foreign reserves. Second, anticipating currency depreciation, creditors may preemptively withdraw funding, triggering banking crises forcing central bank intervention. Intervention depletes reserves, validating anticipated depreciation. Multiple self-fulfilling expectations among depositors, creditors, and currency speculators interact, creating compound vulnerability characteristic of emerging market crises.

Chang-Velasco configuration introduces explicit liquidation choice, generalized endowment a, fire-sale parameter r, and separated debt constraints enabling maturity structure analysis. Financial vulnerability becomes multi-dimensional through illiquidity measures z^+, z^a, z^b, each incorporating impatient fraction π, borrowing capacity f, fire-sale costs r, investment scale $a + d^*$, and debt maturity. When any measure exceeds zero, multiple equilibria arise. Good equilibria implement efficient risk sharing through pooling when confidence prevails. Conversely, bad equilibria emerge from depositor panics (classical bank runs), creditor rollover refusals (short-term debt crises), lending cutoffs (sudden stops), and speculative attacks under fixed rates. Ordering $z^+ < z^a < z^b$ demonstrates systematic vulnerability gradations, with short-term debt creating most fragile configurations. Open economy specifications demonstrate how consumer liquidity demand interacts with world capital markets and foreign borrowing limitations, creating exposure to banking crises, creditor coordination failures, and currency pressures under fixed exchange rates.

Appendix B: Equivalence between household liquidity demand and firm liquidity demand

(a) The Diamond-Dybvig model

Consumers routinely hold substantial amounts of liquid assets to insure themselves against liquidity shocks. Indeed, they confront persistent uncertainty surrounding the economic fluctuations that impact their income streams and investment payoffs. Households and firms thus compete for the economy's available stock of liquidity. Extensive literature has focused on consumer liquidity demand, with foundational contributions by Bryant (1980) and Diamond and Dybvig (1983). In parallel, producer liquidity demand has been developed, most notably by Holmström and Tirole (1998). Under specific conditions, these two approaches are mathematically equivalent, as demonstrated by Holmström and Tirole (2011). Following their demonstration, this section establishes the formal correspondence between household liquidity risk and firm liquidity risk. To this end, exposition begins with the Diamond-Dybvig model, maintaining notational consistency with standard specifications while facilitating comparison with corporate liquidity management.

Timing. Consistent with the producer model, three dates structure the economy, $t = 0,1,2$.

Consumer preferences. Agents are ex ante identical. For notational simplicity, assumption is made that consumption demand is absent at date 0, so each individual invests entire endowment a at the initial date (with no subsequent endowment at other dates). Consumers do not know their type at date 0, which they only learn at date 1. Nonetheless, in the absence of aggregate uncertainty, each fraction is deterministic and known in advance. Fraction $1 - \pi$ is impatient, valuing consumption exclusively at date 1. Remaining fraction π is patient, indifferent between consuming at dates 1 or 2. Formally, state-contingent preferences over consumption C_1 at date 1 and C_2 at date 2 are $u(C_1)$ (if impatient, with probability $1 - \pi$) and $u(C_1 + C_2)$ (if patient, with probability π), respectively, where function u is increasing, strictly concave, with $u'(0) = \infty$. Consumers do not know their type at date 0.

Technology. At date 0, portfolio allocation occurs between liquid short-term projects and illiquid long-term projects. Investment in liquidity carries opportunity cost since long-term projects offer superior returns. Short-term projects yield 1 per unit of date-0 investment one

period later. Long-term projects yield nothing if liquidated at date 1 but deliver R at date 2 per unit of date-0 investment, where

$$R < 1. \tag{B.1}$$

The budget constraint incorporates investments in long-term and short-term projects, denoted by ℓ and i respectively,

$$\ell + i = a. \tag{B.2}$$

Under *autarky*, each individual independently solves

$$\max_{\{\ell, i | \ell + i = a\}} \{(1-\pi)u(\ell) + \pi u(\ell + Ri)\}.$$

Optimal allocation sets $\ell = a$ when impatient agents are sufficiently prevalent: $(1-\pi) \geq \pi(R-1)$. Otherwise, interior solutions satisfy marginal balance

$$(1-\pi)u'(\ell) = \pi(R-1)u'\big(\ell + R(a-\ell)\big). \tag{B.3}$$

Decentralized decision-making generates ex post inefficiency. Upon type realization, impatient individuals receive only short-term proceeds ℓ, potentially inadequate for urgent needs. Conversely, patient individuals receive $\ell + Ri$, yet component ℓ represents wasted resources since these agents could wait for superior long-term returns $R > 1$. Each consumer bears idiosyncratic timing risk individually despite aggregate outcomes being deterministic, since exactly fraction $1-\pi$ materializes as impatient with certainty. Absence of coordination prevents exploitation of this predictability.

Coordinated liquidity management through financial intermediation achieves strict Pareto improvements. Understanding gains requires examining autarky's fundamental inefficiency. Patient consumers wastefully hold liquid short-term assets despite preferring illiquid long-term investments given their intertemporal flexibility. Simultaneously, impatient consumers hold illiquid assets despite requiring immediate resources. When there is no aggregate uncertainty, a financial intermediary (e.g., a bank) collecting deposits can direct all short-term proceeds to impatient individuals and all long-term proceeds to patient individuals, eliminating the cross-purpose allocation inherent to decentralized choices.

A social planner observing realized types maximizes representative utility

$$(1-\pi)u(C_1) + \pi u(C_2), \tag{B.4}$$

subject to

$$(1-\pi)C_1 = \ell, \tag{B.5}$$

$$\pi C_2 = Ri, \tag{B.6}$$

$$\ell + i = a. \tag{B.7}$$

Constraint (B.5) requires total consumption by impatient individuals to equal short-term proceeds ℓ. Specifically, fraction $(1-\pi)$ of agents each consuming C_1 demands $(1-\pi)C_1$ units of resources, which must equal available short-term investment ℓ. Constraint (B.6) requires total consumption by patient individuals to equal long-term proceeds Ri. A fraction π of agents, each consuming C_2, demands πC_2 units of date-2 resources, generated by long-term investment i yielding R. Constraint (B.7) exhausts the endowment. Combining these yields consolidated resource constraint

$$(1-\pi)C_1 + \frac{\pi C_2}{R} = a. \tag{B.8}$$

Condition (B.8) captures resource allocation costs. Each unit of impatient consumption costs 1 in date-0 resources, meaning providing C_1 requires short-term investment at unit cost. Each unit of patient consumption costs $1/R$ in date-0 resources. Providing C_2 requires generating date-2 goods, which long-term investment delivers at rate R. Since long-term investment yields R units of date-2 goods per unit invested, producing $(1-\pi)C_2$ units demands $(1-\pi)C_2/R$ units of date-0 investment. Productivity condition $R > 1$ implies financing patient consumption is cheaper per unit as long-term investment exploits superior returns.

Optimal insurance-consumption policy satisfies first-order condition

$$\frac{u'(C_1)}{u'(C_2)} = R. \tag{B.9}$$

Condition (B.9) equates marginal rate of substitution to marginal rate of transformation R. Since $R > 1$ and u is strictly concave (so u' decreases in consumption), (B.9) necessarily implies $C_1 < C_2$. Patient individuals receive more, reflecting superior returns from waiting.

When coefficient of relative risk aversion exceeds unity (equivalently, $u'(C)C$ decreasing in C), first-order condition (B.9) further implies

$$\frac{C_2}{C_1} = R. \tag{B.10}$$

Inequality (B.10) reveals cross-subsidization from patient to impatient consumers. Patient types receive more ($C_2 > C_1$), yet consumption ratio is compressed below return R. Impatient consumers thus receive more than autarky provides, financed by patient consumers accepting less than autarky offers. Optimal policy does not equalize marginal utilities (return differences prevent full equalization) but brings them closer, providing insurance against timing uncertainty. Implementation proceeds through deposit contracts whereby individuals deposit endowment a, acquiring rights to withdraw C_1 at date 1 or, conditional on not withdrawing early, C_2 at date 2.

Similarities with the producer liquidity demand model, examined below, emerge clearly. Pooling proves superior due to insurance across idiosyncratic risk. Long-term investments dominate short-term alternatives, hence liquidity should be hoarded sparingly and dispatched judiciously. Absence of coordination generally gives rise to overprovision of liquidity as agents self-insure individually.

A well-known issue deserving attention is that financial market trading undermines efficient insurance. Preventing trading at date 1 proves necessary for intermediaries to provide efficient insurance (Jacklin, 1987). Consider an entrepreneur using date-0 endowment a to establish a mutual fund investing exclusively in long-term assets, but not issuing shares until date 1. Patient types benefit from withdrawing deposits (receiving C_1), then purchasing fund shares provided prices stay below $(C_1/C_2)R$. An entrepreneur retaining fund shares when patient while selling at price C_1R/C_2 when impatient obtains Ra when patient (exceeding C_2) and $(C_1R/C_2)a$ when impatient (exceeding C_1), strictly dominating deposit contracts. Insurance entails cross-subsidies that financial markets can arbitrage. Maintaining optimal subsidies requires preventing such trading.

(b) Reinterpreting firms as Diamond-Dybvig consumers

Having reviewed the consumer liquidity demand model, formal analysis establishes that, given specific assumptions, producer liquidity demand models become isomorphic to their consumer counterparts. To parallel Diamond-Dybvig, premises are made of no aggregate

uncertainty, with firms operating as net lenders and investing in short-term projects (yielding 1 at date 1) and long-term projects (yielding R at date 2), where $R > 1$.

Consider ex ante identical firms. The representative firm possesses assets A at date 0, investing amount I in an illiquid project where crucially $I < A$. Once more, note carefully that initial investment falls below firm endowment, contrasting with earlier assumptions. Specification is essential, positioning firms as savers allocating net savings exactly as households allocate endowments.

The representative firm faces shock ρ per unit of investment, materializing either at date 1 (probability $1-\pi$, drawn from distribution $F^{ST}(\rho)$) or at date 2 (probability π, drawn from distribution $F^{LT}(\rho)$). Meeting shocks enables project completion, generating return $\rho_1 I$ at date 2. All income is non-pledgeable ($\rho_0 = 0$). Complete non-pledgeability eliminates external financing possibilities, forcing reliance exclusively on internal savings for liquidity provision.

Investors exhibit risk neutrality, providing capital at zero net return. State-contingent policies are feasible since liquidity use is monitored. The representative firm maximizes date-2 proceeds subject to date-0 constraints on savings allocation. Letting $\bar{\rho}^{ST}$ and $\bar{\rho}^{LT}$ denote cut-off levels (maximum shocks accommodated at each date), the program becomes

$$\max_{\{I,\rho^{ST},\rho^{LT}\}} \{[(1-\pi)F^{ST}(\bar{\rho}^{ST}) + \pi F^{LT}(\bar{\rho}^{LT})]\rho_1 I\} \tag{B.11}$$

subject to budget constraint

$$I + \left[(1-\pi)\int_0^{\bar{\rho}^{ST}} \rho f^{ST}(\rho)d\rho + \frac{\pi}{R}\int_0^{\bar{\rho}^{LT}} \rho f^{LT}(\rho)d\rho\right] I \leq A. \tag{B.12}$$

Budget constraint (B.12) has three components. First term I represents illiquid project investment. Second term captures liquidity provision costs. For short-term shocks (probability $1-\pi$), mean liquidity per investment unit equals $\int_0^{\bar{\rho}^{ST}} \rho f^{ST}(\rho)d\rho$ (average shock conditional on $\rho \leq \rho^{ST}$). Financing requires short-term investment costing 1 per unit. For long-term shocks (probability π) , mean liquidity per investment unit equals $\int_0^{\bar{\rho}^{LT}} \rho f^{LT}(\rho)d\rho$. Financing uses long-term investment yielding R, costing $1/R$ per unit.

Structure mirrors household constraint where date-1 liquidity is expensive (coefficient 1), date-2 liquidity is cheap (coefficient $1/R$) through exploiting superior returns.

The solution minimizes cost of bringing one investment unit to completion

$$\min_{\{\bar{\rho}^{ST},\bar{\rho}^{LT}\}} \left\{ c = \frac{1 + (1-\pi)\int_0^{\bar{\rho}^{ST}} \rho f^{ST}(\rho)d\rho + \frac{\pi}{R}\int_0^{\bar{\rho}^{LT}} \rho f^{LT}(\rho)d\rho}{(1-\pi)F^{ST}(\bar{\rho}^{ST}) + \pi F^{LT}(\bar{\rho}^{LT})} \right\}. \tag{B.13}$$

The numerator represents total cost, combining investment and liquidity. The denominator represents continuation probability. Optimal cut-offs satisfy

$$\bar{\rho}^{ST} = \frac{\bar{\rho}^{LT}}{R} = c. \tag{B.14}$$

Condition (B.14) equates marginal costs across dates. Providing one date-1 liquidity unit costs 1. Providing R date-2 liquidity units costs 1. Efficiency requires equalizing marginal cost per unit delivered.

The connection to Diamond-Dybvig now becomes transparent. Since their results depend on stationary preferences (identical utility functions across types), proper comparison requires identical shock distributions

$$f^{ST}(\rho) = f^{LT}(\rho) \equiv f(\rho) \text{ for all } \rho. \tag{B.15}$$

Stationarity assumption (B.15) ensures timing uncertainty constitutes the sole source of heterogeneity, abstracting from differences in shock distributions themselves. Just as households face identical utility functions regardless of type realization, firms face identical shock distributions regardless of timing realization. Assumption isolates the pure timing mismatch between liquidity needs and resource availability.

For optimal investment I, define net savings $a \equiv A - I$ alongside quantities

$$\begin{cases} C_1 = \left[\int_0^{\bar{\rho}^{ST}} \rho f^{ST}(\rho)d\rho\right] I \\ C_2 = \left[\int_0^{\bar{\rho}^{LT}} \rho f^{LT}(\rho)d\rho\right] I \end{cases} \tag{B.16}$$

Taking on the endowment role, the variable a provides net savings for liquidity management. Variables C_1 and C_2 represent mean liquidity disbursements, analogous to consumption. Substituting (B.16) into (B.12) yields

$$\pi C_1 + \frac{(1-\pi)C_2}{R} \leq a, \tag{B.17}$$

identical to consumer constraint (B.8). Structural equivalence is complete. Entrepreneur's payoff equals

$$[(1-\pi)F^{ST}(\bar{\rho}^{ST}) + \pi F^{LT}(\bar{\rho}^{LT})]\rho_1 I. \tag{B.18}$$

Formal isomorphism requires constructing pseudo-utility. Since objective maximizes continuation probability times return, and this depends on liquidity provision, define $u(\cdot)$ implicitly by

$$u\big(C(\bar{\rho})\big) \equiv F(\bar{\rho})\rho_1 I \tag{B.19}$$

where

$$C(\bar{\rho}) = \left[\int_0^{\bar{\rho}} \rho f(\rho) d\rho\right] I. \tag{B.20}$$

Function $u\big(C(\bar{\rho})\big)$ represents surplus for liquidity $C(\bar{\rho})$. Since $\rho_0 = 0$ (complete non-pledgeability), observe that $u(C_t)$ equals surplus when liquidity needs arise at date t. Verifying pseudo-utility properties requires differentiation. Applying the chain rule to (B.19) establishes

$$\frac{du}{d\rho} = f(\rho)\rho_1 I, \frac{dC}{\rho_0} = \rho f(\rho) I. \tag{B.21}$$

First derivative equals

$$u'C(\bar{\rho}) = \frac{du/d\rho}{dC/d\rho} = \frac{f(\rho)\rho_1 I}{\rho f(\rho) I} = \frac{\rho_1}{\bar{\rho}} > 0. \tag{B.22}$$

Second derivative equals

$$u''C(\bar{\rho}) = \frac{d}{dC}\left(\frac{\rho_1}{\bar{\rho}}\right) = \frac{d}{dC}\cdot\left(-\frac{\rho_1}{\rho^2}\right) = \frac{1}{\rho f(\rho) I}\cdot\left(-\frac{\rho_1}{\rho^2}\right) = -\frac{\rho_1}{\bar{\rho}^3}. \tag{B.23}$$

Pseudo-utility is increasing and strictly concave. Central insight emerges that, despite risk neutrality over monetary outcomes, credit constraint ($\rho_0 = 0$) endogenously generates strict concavity mapping liquidity to surplus. Inability to pledge creates functional risk aversion despite primitive risk neutrality. Entrepreneurs exhibit risk aversion over liquidity despite being risk neutral over money.

Analysis turns to cross-subsidies and Jacklin critique applicability. Cross-subsidies exist provided

$$RC_1 > C_2, \tag{B.24}$$

or equivalently, from (B.20),

$$R\left[\int_0^{\bar{\rho}^{ST}} \rho f^{ST}(\rho)d\rho\right] > \int_0^{R\bar{\rho}^{ST}} \rho f^{ST}(\rho)d\rho. \tag{B.25}$$

Recall consumer cross-subsidies exist when relative risk aversion exceeds unity:

$$-\frac{u''(C)C}{u'(C)} > 1. \tag{B.26}$$

Using (B.19) and (B.20), producer analog becomes

$$-\frac{u''\big(C(\rho)\big)\cdot C(\rho)}{u'\big(C(\rho)\big)} = \frac{\int_0^{\rho} \rho f(\rho)d\rho}{\bar{\rho}^2 f(\bar{\rho})}. \tag{B.27}$$

Producer cross-subsidy condition therefore is

$$\frac{\int_0^{\bar{\rho}} \rho f(\rho)d\rho}{\bar{\rho}^2 f(\bar{\rho})} > 1. \tag{B.28}$$

Establishing equivalence between (B.25) and (B.28) proceeds as follows. Fix ρ and consider

$$H(R) \equiv R\int_0^{\bar{\rho}} \rho f(\rho)d\rho - \int_0^{R\bar{\rho}} \rho f(\rho)d\rho. \tag{B.29}$$

Clearly $H(1) = 0$ since both integrals coincide when $R = 1$. Derivative equals

$$H'(R) = \int_0^{\bar{\rho}} \rho f(\rho)d\rho - \bar{\rho}^2 R f(R\bar{\rho}). \tag{B.30}$$

Showing $H(R) > 0$ for $R > 1$ requires verifying $H'(R) > 0$ whenever $H(R) = 0$. When $H(R) = 0$, equality $R\int_0^{\bar{\rho}} \rho f(\rho)d\rho = \int_0^{R\bar{\rho}} \rho f(\rho)d\rho$ holds. Condition $H'(R) > 0$ then requires

$$\int_0^{R\bar{\rho}} \rho f(\rho)d\rho > R^2\bar{\rho}^2 f(R\bar{\rho}). \tag{B.31}$$

Dividing by $R^2\bar{\rho}^2 f(R\bar{\rho})$ and substituting $\tilde{\rho} = R\rho$ recovers (B.28). Cross-subsidies exist in producer model under precisely identical conditions as consumer model. The demonstration is complete, showing that when firms are net lenders, the producer model is isomorphic to the consumer model.

Jacklin critique applicability requires distinguishing average from marginal subsidies. Cross-subsidy notion above concerns averages. Under (B.28), average cross-subsidy takes form

$$\int_0^{\bar{\rho}^{ST}} \rho f(\rho) d\rho > \frac{\int_0^{\bar{\rho}^{ST}} \rho f(\rho) d\rho}{R}. \tag{B.32}$$

From (B.14) by contrast, no subsidy exists at the margin:

$$\bar{\rho}^{ST} = \frac{\bar{\rho}^{LT}}{R}. \tag{B.33}$$

Suppose firm contracts for credit line permitting withdrawal up to $\bar{\rho}^{ST} I$ at date 1 or $\bar{\rho}^{LT} I$ at date 2. A firm learning at date 1 that shocks materialize only at date 2 evaluates early withdrawal plus reinvestment at rate R versus waiting. Early withdrawal yields $\bar{\rho}^{ST} I$, producing $R\bar{\rho}^{ST} I$ when reinvested. Waiting yields $\bar{\rho}^{LT} I$. From (B.33), these are identical: $R\bar{\rho}^{ST} I = \bar{\rho}^{LT} I$. Firms remain indifferent—no arbitrage exists. Thus, absent alternative opportunities, Jacklin critique does not apply.

In consumer settings, Jacklin critique assumes unmonitored balance sheets. If entrepreneurs can falsely claim high shocks, fully withdraw, reinvest at R, and consume proceeds without repaying investors, identical vulnerability emerges. However, corporate accounts face greater monitoring than household finances. Extreme diversion described above is not ordinary corporate behavior, though firms retain some discretion over liquid resources.

Equivalence demonstration concludes under specified conditions: net lending ($I < A$), full non-pledgeability ($\rho_0 = 0$), distributional stationarity. Net borrower configuration ($I > A$), empirically standard and analyzed in main text, generates qualitatively distinct effects. When the corporate sector is a net borrower, limited pledgeability $\rho_0 < 1$ restricts investment through equity multiplier, creates ex ante and ex post credit rationing, introduces trade-offs between scale and continuation and generates predictions about investment collapse following liquidity shocks and balance sheet propagation lying outside household scope.

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