Information-Concealing Credit Architecture

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Abstract

When the value of a pledgeable asset (or project) is uncertain, investors are tempted to examine it. The information cost is ultimately borne by the asset owner, reducing her financing capacity. A pecking order emerges. Debt generates a greater financing capacity than equity: unlike equity investors who own the asset directly, creditors own the asset only if the borrower defaults and, therefore, have weaker incentives to acquire information. Probabilistic asset ownership can be further diluted by introducing intermediaries between the borrower and the creditor, leading to a new theory of financial intermediation and credit chains. We demonstrate that the optimal financial architecture involves systematically sequencing multiple intermediaries with heterogeneous information costs and asset correlations, rationalizing the seemingly excessive complexity of intermediated credit flows.

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1 Introduction

The financial system operates through a highly intricate network of intermediated funding and collateral flows.[1] The complexity of credit intermediation has been widely criticized for its opacity, which induces contagion by obscuring systemic vulnerabilities, creates significant regulatory challenges, and complicates crisis management efforts.[2] While this seemingly excessive complexity and opacity are often framed as either a byproduct of risk distribution or an intentional attempt to obscure excessive risk-taking, we argue that complex credit flows involving a network of intermediaries maximize credit capacity for the real economy. This result constitutes a cautionary tale for regulators that aim to enhance transparency, as they must also consider the unintended consequences of reducing financing capacity.

How can an asset or a project be used to maximize credit capacity? If there is uncertainty about its exact value but such uncertainty is symmetric between the borrower and lender, then the maximum capacity is achieved "in the dark:" credit based on the expected value of the asset (an *information-insensitive loan*) is higher than the expected credit conditional on the realized value (an *information-sensitive loan*). This is generally the case once the cost of acquiring information about the realized value is taken into account. To sustain information-insensitive loans, however, lenders must be willing to lend "in the dark" against an asset's expected value without the incentive to examine its true value before credit takes place so as to exploit such superior information.

We show a lender is willing to lend in the dark, "no questions asked," when the asset or project has certain properties, such as low uncertainty in its value or high information acquisition cost, which points towards the role of designing the asset itself that has been analyzed in the existing literature.[3] The lender is also willing to lend in the dark when the likelihood of ending up in possession of the asset is low. This last dimension is the one we highlight in this paper.

[1]This structure has been widely documented and explored by Aguiar et al. (2016).

[2]FRBNY (2020) provides a recent policy discussion on systemic vulnerability. Initiatives such as the G20-led push for central clearing and EU's "Simple, Transparent, Standardized" securitization framework reflect a consensus on curbing complexity (e.g., G20 (2018); EU (2022)). Living wills and reforms, such as the UK's ring-fencing regime, illustrate attempts to facilitate crisis management under complex fund flows (e.g., Dallas Fed (2012); PRA (2022)).

[3]See a discussion of how the design of collateral assets, such as pooling or tranching assets, can discourage costly information acquisition in Chapter 2 of Gorton and Ordonez (2023).

We highlight such incentives by proposing a setting in which debt and equity only differ in the likelihood that the funding provider ends up owning the borrower's asset. This asset can correspond to capital that sustains a firm's production, a financial asset, real estate, or projects with verifiable and contractable cash flows. Obtaining funds by issuing equity is akin to selling the asset: the investor *always* ends up owning the asset. Instead, issuing debt implies the lender obtains the asset only if the borrower defaults; the lender *does not always* end up owning it. In summary, different from equity, debt carries a *probabilistic asset ownership*.

This difference in the likelihood of owning the asset implies that equity introduces stronger incentives to acquire information than debt. As a result, a pecking order emerges. Financing capacity is constrained by incentive compatibility (IC) for information-insensitive contracts, because the investor's incentive to acquire information increases with funding. The incentives to acquire information are weaker with debt, relaxing the IC constraints and enlarging financing capacity.

There are situations, however, in which Modigliani-Miller applies, and debt and equity are identical. At one extreme, if the cost of information is so high that the investor would not acquire information, financing capacity would be the same with *information-insensitive* debt and equity. At the other extreme, if the cost of information is so low that the borrower prefers to compensate for the investor's cost of information than to discourage information production, financing capacity would be the same with *information-sensitive* debt and equity. These extreme cases are not our focus. We characterize the parameter conditions under which *information-insensitive* debt dominates equity and information-sensitive securities and thus maximizes the financing capacity by reducing the funding provider's incentives to produce information and saving the information cost.

Our notion of a pecking order differs greatly from that of Myers and Majluf (1984). They show a hierarchical financing strategy given the degree of information asymmetry between the firm and investors: managers know more about their company's prospects than investors. In their work, the extent of information asymmetry is exogenous and fixed, and the choice of which security to issue is based on the degree of adverse selection. We depart from the presumption of asymmetric information, which can be overcome by examining the asset. It is not the *exogenous asymmetric information* that drives the pecking order but instead the *endogenous information production*.

After establishing the optimality of information-insensitive debt, we show that designing an intermediation chain can increase credit by further diluting probabilistic asset ownership. Our analysis speaks directly to the complexity of credit flows intermediated by various financial institutions and demonstrates how such complexity enlarges the financing capacity for the end borrower. Consider an intermediary that extends a loan to *an end borrower* and borrows from *an end lender* pledging the loan as collateral. Only when both the end borrower and intermediary default do the end lender take possession of the asset. If we assume, realistically, that the intermediary's insolvency is not perfectly correlated with that of the end borrower (for example, due to the intermediary holding other assets), the probability of both the end borrower and intermediary going bankrupt is lower than the borrower alone going bankrupt. As a result, the end lender's probability of owning the asset declines in the presence of an intermediary. But how about the intermediary's incentives to acquire information? These are weaker than that of the lender in the absence of intermediation: for the intermediary to own the end borrower's asset, two events must happen—the borrower defaults and the intermediary itself survives—which has a lower probability than the single event of the borrower's default. Therefore, under intermediated financing, both the end lender and the intermediary have weaker incentives to produce information than the lender under direct financing.

Here the intermediary does just that. It intermediates. It does not introduce commitment or expertise as in other theories of intermediation. Why is its participation beneficial? In essence, the intermediation chain dilutes the possibility that any given party ends up with the asset, discouraging any party's examination of the asset. The presence of an intermediary whose portfolio is not perfectly correlated with the borrower's asset—that is, it can survive in situations in which the borrower cannot—distributes the likelihood of the borrower's default and that of taking possession of the borrower's asset among two parties (the intermediate lender, i.e., the intermediary, and the end lender who ultimately provides funds), reducing both parties' incentives to acquire information.

Does this logic of distributing the asset possession probability among lenders on the credit chain imply that the chain should include as many intermediaries as possible? Should the current chain not achieve the maximum borrowing capacity for the end borrower, i.e., the expected value of her backing asset, we show that extending the chain to enlarge credit capacity requires inserting an additional intermediary into the "*chain's bottleneck*": the link has the smallest funding capacity as the lender in the link has the strongest incentive to produce information among all lenders on the chain. Inserting an intermediary into the bottleneck link does not change the probability of asset possession for the preceding intermediaries ("upstream") but unequivocally reduces the probability of asset possession for all the subsequent lenders ("downstream"). We show that, as long as the new intermediary is less tempted to produce information than the bottleneck's lender (i.e., it has a higher information cost or a lower survival probability conditional on receiving the asset), its addition to the chain enlarges its capacity to channel funding.

When the chain is being extended and multiple intermediaries satisfy the condition above, which intermediary should be included? This problem is challenging because inserting an intermediary affects whether and which intermediaries will be included in the subsequent steps of chain extension. A local optimum may not be the global optimum. First, we show that an optimal chain should equalize the incentives to acquire information across lenders in all links, so to avoid bottlenecks. The intuition is similar to that of maximizing the Leontief production function. In a setting in which intermediaries differ in costs of information production and survival probabilities conditional on receiving the end borrower's asset (i.e., the two forces that drive the incentives to produce information), intermediaries with low information costs should be placed later on the chain so that their probability of asset possession is low, while lenders with high information costs can be placed earlier, because even though this makes them more like to receive the asset (as they face more directly the end borrower's default), their high information cost discourages information production. In a simpler setting where intermediaries have the same information costs, those most correlated with the end borrower are placed earlier in the chain. Importantly, we demonstrate that the optimal chain emerges endogenously in a laissez-faire environment, reflecting exactly this principle.

Our model suggests that the formation of a long credit chain is meaningful only when intermediaries hold heterogeneous and imperfectly correlated assets. For the intuition, consider instead a scenario of homogeneous and independent assets—that is, conditional on the end borrower's default, intermediaries have independent and identical survival probabilities. The optimal chain only needs one intermediary: while inserting more intermediaries weakens the incentive to produce information for the downstream lenders, but the bottleneck remains between the end borrower and the first intermediary, whose probability of receiving the asset (i.e., the end borrower's default) does not change and the conditional survival probability is the same under the i.i.d. assumption. In contrast, when intermediaries hold heterogeneous and correlated assets, there is room for the chain to enlarge funding capacity by involving many intermediaries and properly sequencing them.

While our main analysis takes as given the risk profile of the end borrower's asset and assets of the intermediaries, it has unique implications for endogenous asset choices. We demonstrate that an equilibrium exists in which an intermediary may forgo productive investments and opt for safe assets ("bonds") for two reasons. First, when the intermediary raises funds from a lender by pledging bonds as collateral, those safe bonds do not induce information production by the lender thereby enlarging the intermediary's fund-raising capacity. Second, when the intermediary lends to a borrower, holding bonds allows it to stay uninformed about the borrower's asset, because, due to the lack of expertise in examining risky assets, the intermediary faces a high information cost.

Relation with the literature. At the core of our model is a simple observation: debt carries a probabilistic ownership of the backing asset. Since the funding provider's cost of examining the asset is ultimately borne by the borrower, the borrower's financing capacity is maximized under information-insensitive contracts, and debt dominates equity (full asset ownership) because it induces weaker incentives for the funding provider to acquire information. Our pecking-order theory of capital structure differs from Myers and Majluf (1984). Importantly, it generates new and unique implications on financial intermediation: financing capacity is enlarged when the probability of owning the backing asset is diluted by inserting intermediaries between the borrower and the funding provider. We provide a new view of financial intermediation: it does not generate information but conceals it with the help of opaque funding networks. The only role of intermediaries is to be there and intermediate. Intermediaries do not have any expertise in our model.

Our work is related to Diamond (1984) who shows that by diversifying portfolios, banks can dilute the need to monitor upon default and improve credit provision. In our model, the "diversification" happens along credit chains. It is not about diversifying across different assets but instead, given an asset, credit chains distribute (probabilistic) asset ownership across lenders along the chains, reducing their incentive to acquire costly information and thus enlarging credit capacity.

Our model complements studies that emphasize designing opaque assets and institutions to provide liquidity and facilitate credit. In Dang et al. (2017), for instance, banks improve on credit provision by making their assets as opaque as possible. We show that instead of making intermediaries opaque, forming intermediary networks also enhances opaqueness and enlarges credit capacity. The seemingly spurious interconnectedness is created to conceal information.

Our theory also offers a new rationale for understanding intermediaries' asset correlation. In Farhi and Tirole (2012), financial intermediaries correlate their portfolios to increase the probabilities of government bailout in case of default, as those defaults would happen in tandem. In our case, asset correlation lays the foundation for credit chains to emerge. A chain increases its capacity to channel funds by properly sequencing correlated and yet heterogeneous intermediaries. Highly correlated intermediaries are positioned upstream (closer to the end borrower), because even though their probabilities of receiving the end borrower's asset are high, their probabilities of survival conditional on the end borrower's and preceding intermediaries' insolvency are low. The less correlated intermediaries are positioned downstream. Their low probability of receiving the asset counterbalances high conditional survival probabilities in deterring information production.

Therefore, beyond a theory of capital structure and financial intermediation, our model highlights two new sources of ex-ante heterogeneity among intermediaries—information cost and conditional survival probabilities—that lead to endogenous network formation. Note that the relevant conditioning event for intermediaries' survival is the insolvency of the end borrower and all preceding intermediaries on credit chains, which is chain-specific and thus differs from other measures of intermediaries' financial health in the existing literature.[4] Moreover, our focus is on the formation of intermediation networks (chains) rather than how networks propagate shocks ex-post.[5]

Our paper emphasizes that intermediation chains weaken incentives to obtain informational advantage and create information asymmetry. Glode and Opp (2016) and Glode, Opp, and Zhang (2019) take information asymmetry as given and study how intermediation chains mitigate the as-

[4]In the existing literature, bank heterogeneity in liquidity needs or investment opportunities leads to the formation of interbank credit or insurance networks (e.g., Allen and Gale, 2000; Brusco and Castiglionesi, 2007; Afonso and Lagos, 2015; Babus, 2016; Corbae and Gofman, 2019; Craig and Ma, 2022; Farboodi, 2023).

[5]Please refer to Jackson and Pernoud (2021) for a literature review on shock propagation.

sociated inefficiency. Furthermore, in their papers, intermediaries (dealers) facilitate asset trading in spot markets, while, in our model, intermediaries sign bilateral (debt) contracts.[6]

A recent body of literature examines credit chains. Our model differs in that intermediaries neither possess expertise nor have unique access to markets or trading relationships. Intermediaries are just there to dilute the probabilistic asset ownership along credit chains. Moreover, we do not assume a particular financing contract (debt) to be optimal; based on the fact that debt carries probabilistic asset ownership, we derive a complete theory of debt optimality, credit intermediation, and credit chains. Among the related papers on credit chains, Maggio and Tahbaz-Salehi (2014) study how the distribution of collateral along predetermined credit chains affects funding capacity and systemic stability. In Donaldson and Micheler (2018), credit chains arise to mitigate liquidation losses when banks rely on non-resaleable debt (e.g., repo). In He and Li (2022), the intermediation chain emerges to address maturity mismatch and costly liquidation associated with the failure to roll over debts. Donaldson, Piacentino, and Yu (2022) study financial stability implications of chains of long-term debts that allow borrowers to dilute existing creditors' claims by issuing new debts. Glode and Opp (2023) study debt renegotiation on a predetermined credit chain.[7]

One form of issuing debt backed by the borrower's asset is a repurchase agreement (repo). Note that repo requires spot exchange of both cash and collateral, while in our model, only cash exchange (from the lender to the borrower) is necessary. Issuing equity corresponds to raising funds by selling the asset. Under this interpretation, our model speaks to the superiority of repo over asset sale as a way of raising funds. Our explanation differs from Parlatore (2019), who argues that firms would rather pledge financial assets as collateral than sell them when the return on firms' investment is not observed, the asset is not liquid, or the investment opportunities are persistent. Our theory also differs from Monnet and Narajabad (2012) who emphasize bilateral trading frictions. In our model, all of these frictions are absent. The key to understanding why debt

[6] Chains of spot asset exchanges also emerge in models of over-the-counter (OTC) markets, often in the absence of informational frictions (e.g., Viswanathan and Wang (2004); Gofman (2014); Atkeson et al. (2015); Chang and Zhang (2015); Wang (2016); Babus and Kondor (2018); Hugonnier et al. (2019); Sambalaibat (2019); Hendershott et al. (2020); Colliard and Demange (2021); Shen et al. (2021)).

[7] Beyond the literature on credit chains, recent studies also analyze the chain of delegated (equity) asset management (e.g., Dasgupta and Maug (2021); Zhong (2023)). Their focus is on asset managers' differences in skills.

dominates equity—and, relatedly, why repo dominates asset sales as a means of raising funds—lies in the distinction between probabilistic asset ownership under debt and full asset ownership under equity. Probabilistic asset ownership weakens information-production incentives.

In our model, credit chains that emerge in equilibrium reflect repo and collateral rehypothecation, a common phenomenon, particularly in the lead-up to the global financial crisis (GFC) (e.g., Fuhrer, Guggenheim, and Schumacher (2016); Gorton, Laarits, and Muir (2022)). The driving force of weakening information-production incentives through the dilution of asset ownership is distinct from those in the existing studies. Several papers emphasize cash lenders' default (failure to return collateral) (e.g., Eren (2014); Infante (2019); Kahn and Park (2019); Infante and Vardoulakis (2020); Maurin (2022)). Rehypothecation arises from collateral scarcity when agents face liquidity constraints (e.g., Andolfatto, Martin, and Zhang (2017); Jank, Moench, and Schneider (2022); Infante and Saravay (2024)) or to relax leverage and short-sale constraints (e.g., Bottazzi, Luque, and Páscoa (2012), Gottardi, Maurin, and Monnet (2019), Brumm et al. (2023)).

Finally, our work contributes to the ongoing discussion about the desirability of complex financial systems. While most of this literature has highlighted the negative consequences of such complexity, such as Stiglitz (1999) and Caballero and Simsek (2013), we instead emphasize the rationale for such complexity to improve credit provision in the economy.

The next section introduces a model of capital structure where costly information acquisition and the probabilistic ownership of debt give rise to a pecking of debt over equity. In section 3, we discuss the benefits of intermediation, and section 4 characterizes the optimal intermediation chain structure with multiple heterogeneous intermediaries. We make the final remarks in the last section.

2 Optimal Financing

We analyze a general problem of financing liquidity needs when the value of pledgeable assets is uncertain. In this section, we focus on a firm borrowing from a deep-pocket investor (the end lender if channeled under a debt contract). In the next section, we allow for a richer environment with multiple firms that form intermediation networks.

The economy has three dates, $t = 0, 1$, and 2. There are two agents: a firm and a deep-pocket investor. They are risk-neutral with a zero discount rate. At $t = 0$, the firm has endowment K, which is fully invested in a project. This investment involves capital and real estate needed for the firm's operation and represents pledgeable assets with liquidation value U at $t = 2$. We will assume later U is uncertain at $t = 0$. The project also generates nonpledgeable, stochastic profits: with probability q, the project does not generate any profit, and with probability $(1-q)$, it generates $A > 1$ per unit of investment. We assume, however, that at $t = 1$ the firm may be hit by a liquidity shock with probability λ. In this case, the firm needs to raise new funds to maintain operations, possibly at a reduced scale. In particular, if the firm raises $L \in [0, K]$ it can operate at a scale that is L/K of the original, and obtain profits AL if successful. This timeline is illustrated in Figure 1.

2.1 The Setup

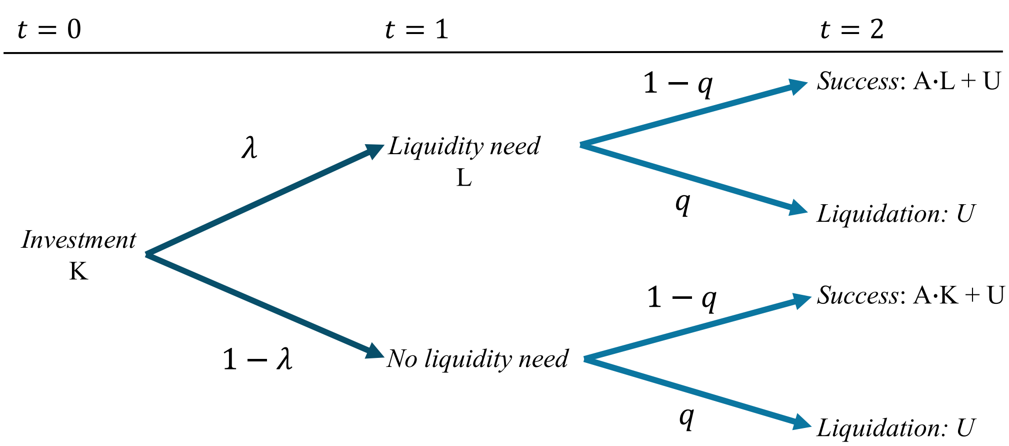

Figure 1: **Project timeline.** This figure illustrates the timeline of the project.

We assume that the pledgeable value, U, is uncertain and equal to G with probability p and B ($< G$) with probability $1 - p$. Let $\bar{U}$ denote the expected liquidation or collateral value

$$\bar{U} = pG + (1 - p)B. \tag{1}$$

Without the uncertainty in U, the model is rather standard. We introduce the uncertainty in U

so that we can meaningfully discuss information acquisition and its implications on financing capacity and the optimal financing contracts and financial architecture (the nexus of contractual relationships in the presence of multiple firms or financial intermediaries).

The information environment is specified as follows. At $t = 1$, the firm does not know whether the liquidation value is G or B. At $t = 1$, the investor does not know the liquidation value either but can learn about it by paying a cost, C. Once she knows the liquidation value, the information is revealed to the firm as well. At $t = 2$, the firm knows whether the project succeeds, but the investor does not and cannot learn about it. In contrast with the standard costly verification model (Townsend (1979)), in which the lender can learn about the success or failure at a cost, here the lender cannot. Instead, the investor may learn about the liquidation value at a cost.

We made several assumptions that focus on our information mechanism. First, the firm has to invest its whole endowment to start the project at $t = 0$, so it cannot self-insure against the liquidity shock at $t = 1$. We also rule out external financing at $t = 0$ to focus solely on the problem of external financing at $t = 1$ should a liquidity shock hit. Second, the project always has a pledgeable liquidation value of U that is independent of the liquidity shock or the project's success. Third, the cash flows from a successful project—AK without being hit by the liquidity shock and AL after the liquidity shock—cannot be pledged for external financing. These assumptions guarantee that the firm's financing capacity is tied to the uncertain value of U, while its incentive to raise financing, L, in the liquidity event (to generate AL) is tied to productivity A. Such separation allows a transparent exposition of our mechanism.[8]

Throughout the analysis, we maintain the following set of parametric assumptions

Assumption 1 (Parametric Assumptions)

- $K \geq G$*: in the liquidity event, financing based on even the highest liquidation value is still insufficient to refinance the project to its original capacity.*

- A *is sufficiently high: the firm wants to maximize refinancing in the liquidity event.*

[8]For interpretation, one may regard the liquidation value as what the investor can repossess, and through the threat of liquidation, the investor enforce the contractual payoff. Alternatively, one may view A as unobservable and unverifiable, and A can also be inalienable from the firm manager's human capital.

Next, we analyze the financing structure of investment in the liquidity event at $t = 1$. We compare equity and debt. In our model, equity represents the investor's *direct ownership* (shares) of U, while debt carries a *probabilistic ownership*—a lender owns U only if the firm defaults on the contractual repayment. We will show probabilistic ownership weakens a lender's incentive to produce costly information, generating a larger financing capacity under debt than equity.

2.2 Equity Financing

The firm issues equity shares of the liquidation value, U. The number of shares is normalized to one. We consider information-sensitive and -insensitive equity. In the former, the investor pays the cost C to learn about U. For the investor to break even, the cost of information acquisition must be covered by the firm, implying financing less than $\bar{U}$. In the latter case, the firm does not need to compensate the investor's information acquisition cost, but financing is limited by an incentive-compatible (IC) condition that prevents the investor from privately acquiring information.

2.2.1 Information-sensitive equity

The firm offers a contract to the investor that specifies the equity price of k_U^s for z_U^s fraction of equity shares, where $U \in \{B, G\}$ and the superscript represents the type of financing contract ("s" for information-sensitive). After the investor acquires information at the cost of C, the value of U is revealed to her and to the firm, and the U-contingent contract is executed. For the investor to participate, the break-even condition must hold:

$$pz_G^s(G - k_G^s - C) + (1 - p)z_B^s(B - k_B^s - C) = 0. \tag{2}$$

It is assumed that the investor breaks even in expectation and all the surplus goes to the firm.

Given Assumption 1 (i.e., A is sufficiently high), the optimal fraction of share issuance is $z_G^s = z_B^s = 1$. The values of k_B^s and k_G^s hence represent the financing the firm can obtain to continue operations if the liquidation value is low or high, respectively. Given the linearity of the constraint, these are indeterminate, so we normalize $k_B^s = B$, which simply implies that the cost of information acquisition is ex-ante compensated if the liquidation value is G. The investor's break-even condition (2) implies $k_G^s = G - C/p$. In words, given a sufficiently high A, the firm is willing to sell the liquidation value that is worth G at a discounted price $k_G^s = G - C/p$ so that the investor breaks even in expectation, taking into account the cost of information production. Note that the cost of information production reduces the firm's financing capacity: under $U = G$, the funds raised are k_G^s, which is below G (the pledgeable liquidation value of the firm's stock).

We assume the firm keeps the full surplus, which is equal to

$$(1-q)\left[p(Ak_G^s - G) + (1-p)(Ak_B^s - B)\right] + q(0 - \bar{U}), \tag{3}$$

where $Ak_G^s - G$, for instance, captures the profits from obtaining funds selling the asset with high liquidation value and continuing operations at a scale k_G^s,with a nonpledgeable return A in case the project succeeds, with probability $1-q$. This scenario happens with probability p and the corresponding situation with low liquidation value with probability $1-p$. If the project fails, the firm loses the liquidation value to the investor. Substituting $k_B^s = B$ and $k_G^s = G - C/p$ into the social surplus, we obtain the following result.

Lemma 1 (Social surplus: information-sensitive equity) *The optimal information-sensitive equity contract generates social surplus* $[(1-q)(A-1)-q]\bar{U} - (1-q)AC$ *in the liquidity event.*

The first part of the social surplus, $[(1-q)(A-1)-q]\bar{U}$, shows that it is increasing in the expected pledgeable (collateral) value, $\bar{U}$. Consistent with our assumption of a sufficiently high A, we maintain $(1-q)(A-1)-q > 0$ through the paper. The second term, $-(1-q)AC$, shows that the cost of information production reduces the surplus by reducing financing capacity and wasting resources on producing information. The cost is higher when the project is more productive, i.e., A is higher, and when it is more likely to succeed, i.e., $1-q$ is higher.

2.2.2 Information-insensitive equity

The firm offers to sell equity at price k^i for a z^i fraction of the liquidation (pledgeable) value, where the superscript, "i", represents information-insensitive. Notice that in this case, there is no subscript as the contract is by construction not conditional on the true liquidation value. For this contract to be feasible, it should be the case that the investor does not have an incentive to deviate and privately learn about U at the cost of C. The equity price, k^i, is set so that the investor breaks even based on the expected liquidation value:

$$k^i = z^i \bar{U} = z^i [pG + (1-p)B]. \tag{4}$$

The investor does not privately produce information if its expected return(the left side below) is lower than the expected return of following the contract without information acquisition (zero profit on the right side below):

$$(1-p)(0-C) + p(z^i G - k^i - C) \leq 0. \tag{5}$$

On the left side, the first term represents the case of $U = B$ where the investor will not buy equity as the payout is below the price, $z^i B < k^i = z^i \bar{U}$, and the second term represents the gain of knowing privately $U = G$ but buying equity at the lower uncertainty price. Rearranging this incentive-compatibility (IC) condition and substituting out k^i using (4), we obtain

$$k^i = z^i \bar{U} \leq \frac{C}{p\left(\frac{G-\bar{U}}{\bar{U}}\right)}, \tag{6}$$

where the right side is a limit on the amount of information-insensitive equity financing the firm can raise. Intuitively, if the information cost is low or the liquidation (pledgeable) value is information worthy (i.e., the percentage deviation of G from $\bar{U}$ is high), the investor is tempted to produce information, so the information-insensitive financing capacity is low. We consolidate such properties of the pledgeable value into one parameter, Γ, given by

$$\Gamma = \frac{1}{p\left(\frac{G-\bar{U}}{\bar{U}}\right)}, \tag{7}$$

so that the IC constraint on financing capacity can be written as

$$k^i \leq \Gamma C, \tag{8}$$

where Γ summarizes the attributes of the pledgeable value that induce information and C is the cost of such information. The lower Γ and C, the higher the incentives to learn about the asset, and the stronger the constraint in raising funds with an information-insensitive equity contract.

The surplus from this contract, which is the information-insensitive counterpart of (3), is

$$(1-q)(Ak^i - z^i\bar{U}) + q(0 - z^i\bar{U}), \tag{9}$$

When $k^i = \bar{U}$ (i.e., the IC constraint (8) is not binding at $z^i = 1$), the social surplus is greater than that given by (3) under information-sensitive equity financing. However, the maximum financing capacity $\bar{U}$ may not be attainable under the IC constraint (8).

Lemma 2 (Social surplus: information-insensitive equity) *The optimal information-insensitive equity contract is subject to the IC constraint (8) that limits z^i, the fraction of equity sold to the investor. Given z^i, it generates social surplus $[(1-q)(A-1)-q]z^i\bar{U}$ in the liquidity event.*

Note that as long as the investor's break-even condition holds, the information-sensitive contract is feasible. The information-insensitive contract requires the additional IC condition (8).

2.3 Debt Financing

Consider a debt contract that specifies the lending amount, the promised repayment, and a covenant on the percentage of liquidation value (collateral) seized by the lender in case there is no repayment.

2.3.1 Information-sensitive debt

The timing is the same as the case of the equity contract. The firm offers a contract that is U-contingent. After receiving the contract, the lender produces information on U, and U is also revealed to the firm. Then the contract is executed under $U = B$ or $U = G$. Information-sensitive debt is feasible as long as the lender's break-even condition holds.

The debt contract is summarized by three variables. The lending amount is denoted by L_U^s, the repayment to the lender is denoted by R_U^s, and the fraction of collateral or liquidation value the lender seizes in default is denoted by x_U^s, where $U \in \{B, G\}$. In the following, we characterize the optimal contract step-by-step.

Given the assumption that A is sufficiently high, and that the firm wants to borrow as much as possible, we set $x_B^s = x_G^s = 1$, This is the firms wants to pledge as much collateral as possible.

Whether the project fails or not is the firm's private information, so the firm may default even if it succeeds.[9] Therefore, a debt contract must induce the firm to tell the truth, and hand the collateral over only when it cannot repay. The truth-telling condition requires $R_G^s = G$ and $R_B^s = B$. Note that for the equity contract, we do not discuss this issue because whether the project fails or succeeds, the lender receives the same payoff given by the liquidation (pledgeable) value.

The lender's break-even (participation) condition equates the expected loan minus the information costs with the expected repayment and default proceedings.

$$pL_G^s + (1-p)L_B^s + C = (1-q)[pR_G^s + (1-p)R_B^s] + q[px_G^s G + (1-p)x_B^s B]. \quad (10)$$

Replacing full collateral pledged ($x_B^s = x_G^s = 1$) and truth-telling conditions ($R_G^s = G$ and $R_B^s = B$), we can rewrite the participation constraint as :

$$pL_G^s + (1-p)L_B^s + C = pG + (1-p)B = \bar{U}. \quad (11)$$

The payments in the two states, $U = B$ and G, are indeterminate, so we fix $L_B^s = B$, and obtain

$$pL_G^s + C = pG, \text{ or, equivalently, } L_G^s = G - \frac{C}{p}. \quad (12)$$

Therefore, we have fully characterized the U-contingent debt contract (L_G^i, R_G^i, x_G^i) and

[9] Note that verifying project outcome is not an issue for equity financing because, whether the project succeeds or fails, the equity investor's share is predetermined.

(L_B^i, R_B^i, x_B^i). For $U = G$, we have $L_G^s = G - \frac{C}{p}$, $R_G^s = G$, and $x_s^G = 1$, and for $U = B$, $L_B^s = B$, $R_B^s = B$, and $x_s^F = 1$. Even though collateral is fully pledged, the expected credit capacity is below the expected liquidation value by the cost of information C.

The social surplus created by the information-sensitive debt is given by

$$p(1-q)\left[AL_G^s - (1-q)R_G^s - qx_G^s G\right] + (1-p)(1-q)\left[AL_B^s - (1-q)R_B^s - qx_B^s B\right]. \quad (13)$$

Lemma 3 (Social surplus: information-sensitive debt) *The optimal information-sensitive debt contract generates social surplus* $[(1-q)(A-1) - q]\bar{U} - (1-q)AC$ *in the liquidity event.*

Lemma 3 states that the social surplus generated by information-sensitive debt is equal to that obtained under information-sensitive equity in Lemma 1. Therefore, our analysis reaches a Modigliani–Miller style result: under costly information acquisition, debt financing and equity financing are equivalent in our setting. Next, we analyze information-insensitive debt and show that meaningful difference emerges between information-insensitive debt and equity and between information-insensitive debt and information-sensitive debt (and equity).

2.3.2 Information-insensitive debt

Next, we consider the scenario in which the lender lends based on the expected liquidation value, and it is incentive-compatible for lender not to produce costly information. Without information on liquidation value, U, the debt contract is no longer contingent on the value of U. It specifies the amount of lending, L^i (the superscript "i" is for information-insensitive), the fraction of liquidation value seized by the lender when the project fails, x^i, and the nominal repayment, R^i. The lender's break-even (participation) condition is,

$$L^i = (1-q)R^i + qx^i[pG + (1-p)B], \quad (14)$$

and the firm's truth-telling condition,

$$R^i = x^i[pG + (1-p)B]. \quad (15)$$

From the borrower's truth-telling condition, we obtain

$$x^i = \frac{R^i}{pG + (1-p)B} = \frac{R^i}{\bar{U}} \leq 1, \tag{16}$$

where the last inequality captures that the firm cannot pledge more than the whole collateral. Substituting this solution of x^i into the lender's participation (break-even) condition, we obtain

$$L^i = R^i. \tag{17}$$

After the firm proposes the debt contract, the lender decides whether to produce information and whether to accept the offer. Therefore, the contract design is subject to the following incentive compatibility constraint:

$$0 \geq (1-p)(0-C) + p[(1-q)R^i + qx^iG - L^i - C]. \tag{18}$$

The left side represents the case without information production as the lender breaks even and earns zero profit. On the right side, if $U = B$, the lender will not lend to the firm as the expected payoff is smaller than the specified lending amount, as shown below:

$$qR^i + (1-q)x^iB = L^i \left[q + (1-q)\frac{B}{\bar{U}} \right] < L^i,$$

where we apply (17) to substitute out R^i and x^i in the first step If $U = G$, the lender will accept the offer, generating positive profits. The positive profits under $U = G$ are directly implied by the break-even in expectation and the loss from lending under $U = B$. Thereby, we have confirmed that under $U = B$, the lender declines the offer, and under $U = G$, the lender accepts the contract.

The incentive compatibility (18) constraint can be simplified to the following inequality that is at the heart of our model and carries several key messages:

$$L^i \leq \frac{C}{qp\left(\frac{G-\bar{U}}{\bar{U}}\right)} = \Gamma\frac{C}{q}, \tag{19}$$

where we use Γ, defined in (7), to summarize the attributes of the project's collateral. As with equity, the left side (financing capacity) is high when it is costly for the lender to acquire information (high C) or the asset does not induce information (high Γ). Importantly, however, with a debt contract, credit capacity is also high when the probability the project fails is low (low q). This is not due to the lender's risk aversion and credit risk being priced in equilibrium. In our model, the lender is risk-neutral. The link between default probability and credit capacity emerges from the lender's information choice. When q is low, it is unlikely that the firm defaults and the lender ends up in possession of the asset, discouraging its examination.

Since A is sufficiently high, the constraint (19) binds, and we have fully characterized the information-insensitive debt contract, (L^i, R^i, x^i):

$$L^i = \min\left\{\bar{U}, \Gamma\frac{C}{q}\right\}, \qquad R^i = L^i, \quad \texttt{and} \quad x^i = R^i/\bar{U} \tag{20}$$

The social surplus, i.e., the firm's profit, is

$$(1-q)(AL^i - R^i) + q(0 - x^i\bar{U}) = [(1-q)(A-1) - q]L^i. \tag{21}$$

Lemma 4 (Social surplus: information-insensitive debt) *The optimal information-insensitive debt contract is subject to the IC constraint (19) that limits L^i, the amount of lending. Given L^i, it generates social surplus $[(1-q)(A-1)-q]L^i$ in the liquidity event.*

2.4 An Informational Theory of the Pecking Order

Comparing the IC constraints (8) and (19) for information-insensitive equity and debt, respectively, we can see that the latter allows for a greater financing capacity when $q < 1$,

$$\Gamma\frac{C}{q} > \Gamma C. \tag{22}$$

While a lender owns the asset with probability q (the probability that the borrower defaults), an equity investor always ends up owning it. Since producing information is more beneficial when the likelihood of owning the asset increases, debt generates a greater financing capacity within information-insensitive contracts. If an information-insensitive equity contract is feasible, an information-insensitive debt contract is also feasible. The reverse is not true.

Now we compare these alternatives. When $\Gamma\frac{C}{q} > \Gamma C > \bar{U}$, the maximum loan among information-insensitive contracts is feasible, and both equity and debt generate the same surplus based on the maximum credit capacity possible, $L = \bar{U}$. However, in the parameter region where $\Gamma\frac{C}{q} > \bar{U} > \Gamma C$, the debt contract generates a greater surplus as it is possible to borrow $\bar{U}$ with debt but not with equity. Therefore, our model generates a new pecking order theory—debt is preferred to equity—based on costly information production.

Now, let's consider the case in which $\Gamma\frac{C}{q} < \bar{U}$. Here information-insensitive debt is constrained by the IC condition, while information-sensitive debt is constrained by compensating the lender for the information cost. The social surplus generated by information-insensitive debt is given by

$$[(1-q)(A-1)-q]L^i = [(1-q)(A-1)-q]\Gamma\frac{C}{q} \tag{23}$$

which is greater than the social surplus generated by information-sensitive debt (or equity), $[(1-q)(A-1)-q]\bar{U} - (1-q)AC$, if and only if

$$\frac{C}{\bar{U}} > \left[\frac{(1-q)A}{(1-q)(A-1)-q} + \frac{1}{p\left(\frac{G-\bar{U}}{\bar{U}}\right)q}\right]^{-1}. \tag{24}$$

The information-insensitive debt dominates if the cost of acquiring information is sufficiently high relative to the expected collateral value, which is more likely to be satisfied when the project productivity, A, is high, when the liquidation value is not information-worthy, i.e., $p\left(\frac{G-\bar{U}}{\bar{U}}\right)$ is low, and importantly, when the probability of default, q, is low.

The next proposition summarizes these results.

Proposition 1 (Pecking order under information choice) *Under costly information production, the optimal financing structure has the following properties:*

1) Information-insensitive debt dominates information-insensitive equity. The IC constraint for *information-insensitive debt is weaker than that for equity under $q < 1$.*

2) *Information-sensitive debt and information-sensitive equity are equivalent.*

3) *Information-insensitive debt dominates information-sensitive debt if and only if the condition (24) holds.*

Discussion: Repo vs. asset sale. Our model not only introduces a new theoretical foundation for the optimal financing structure but also explains why many firms, and in particular, financial firms pledge assets as collateral and issue secured debt (for example, through a repurchase agreement) to raise funds rather than simply sell their assets. Selling assets is equivalent to selling equity, as in both cases, the asset buyer or equity investor takes the full ownership. The incentive to produce costly information is stronger than a secured lender's incentive, because, the lender only takes probabilistic ownership, that is she only receives the asset (collateral) when the borrower defaults. Secured debt reduces the incentive of costly information production and thereby enlarges the funding capacity. Note that in our model, a repurchase agreement (repo) and secured debt are equivalent as both represent a probabilistic ownership of the collateral. In practice, repo requires the borrower to immediately hand over the collateral to the cash lender and retrieves the collateral after making the repayment, while a secured debt contract only requires the borrower to hand over the collateral ex post in default. Such distinction is not meaningful in our model.

3 Endogenous Intermediation

We now extend the environment adding another firm that is ex-ante identical to the one considered in the previous section. We assume that, while the liquidity shock is uncorrelated between the two firms, project failure is. Specifically, the *unconditional probability* of project failure is q for both firms as in the previous section. Given the failure of one firm, however, the *conditional probability* that the other firm also fails is $\phi \in (0, 1)$. When ϕ is close to 1 (zero), the outcomes of the two projects are perfectly positively (negatively) correlated. Under the condition (24), we focus on information-insensitive debt financing.

3.1 Intermediated Financing

When a firm, labeled as "F", is hit by the liquidity shock, the amount of information-insensitive debt it can issue directly to the lender is given by (20). F may also seek intermediated financing: F borrows from the other firm, labeled as "I" (for intermediary), pledging the project as collateral, and I repledges F's project to the end lender. The repledging of collateral can be *implicit* if collateral ownership is transferred upon default at $t = 2$ (usual bank credit), or *explicit* if the collateral is an asset that can be separated from the project's operation (for instance, a financial asset) and it is transferred at $t = 1$ and repurchased at $t = 2$ upon repayment (usual repo agreement with rehypothecation).[10] We will show that such indirect financing, with I as the intermediary, allows F to obtain more funds than direct financing.

The amount of information-insensitive debt I can raise from the end lender is given by

$$L_I = \min\left\{\bar{U},\, \Gamma\frac{C}{q\phi}\right\}. \tag{25}$$

The only difference relative to (20) is that q is replaced by $q\phi$. Conditional on F's default, which happens with probability q, the conditional probability of I's default is ϕ. Therefore, the joint probability of both firms defaulting is $q\phi$. Since the end lender's incentive to acquire information about the liquidation value depends on the probability of receiving the collateral (both firms defaulting), $q\phi$ instead of q shows up in the IC constraint.

Next, consider the amount of information-insensitive debt F can raise from I:

$$L_F = \min\left\{\bar{U},\, \Gamma\frac{C}{q(1-\phi)}\right\}, \tag{26}$$

Here q in the solution (20) is replaced by $q(1-\phi)$, the probability that F defaults and firm I does not. Figure 3 represents these flows and the credit capacity with and without intermediation.

[10] In fact, any form of financial intermediation can be viewed as rehypothecating claims (e.g., Rampini and Viswanathan (2019)). Our model does not distinguish explicit and implicit rehypothecation.

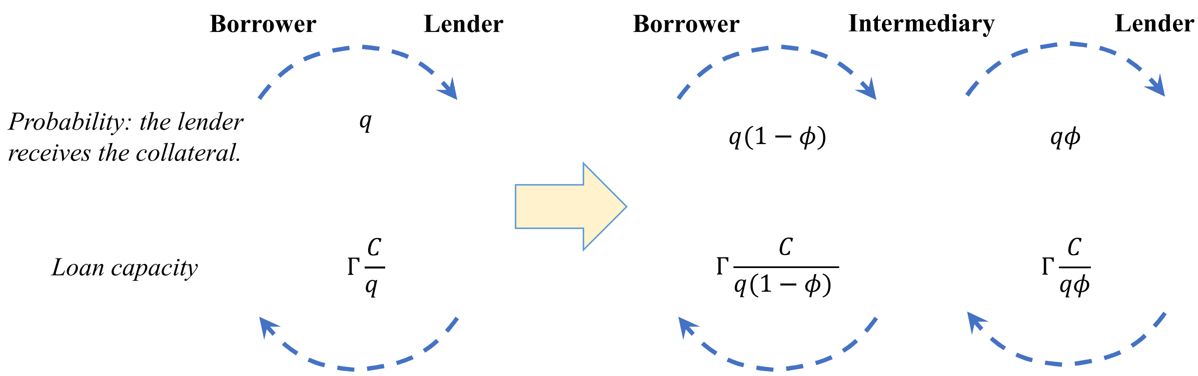

Figure 2: From Direct Financing to Intermediated Financing.

In summary, F's information-insensitive debt capacity is given by

$$L^i = \min\left\{\bar{U},\ L_F,\ L_I\right\} = \min\left\{\bar{U},\ \Gamma\frac{C}{q\phi},\ \Gamma\frac{C}{q(1-\phi)}\right\} = \min\left\{\bar{U},\ \Gamma\frac{C}{\widehat{q}}\right\}, \tag{27}$$

where we define a composite probability

$$\widehat{q} = \max\{q\phi,\ q(1-\phi)\}. \tag{28}$$

Under $\phi < 1$ and $1-\phi < 1$, we have $\widehat{q} < q$ and L^i is greater than the amount of direct financing given by (20). From $\widehat{q} = \max\{q\phi,\ q(1-\phi)\}$, it is clear that intermediated financing achieves a greater funding capacity by diluting both the end lender's and I's incentive to produce information.

The composite probability, $\widehat{q} = \max\{q\phi,\ q(1-\phi)\}$, reflects a funding *"bottleneck"*. A lower ϕ weakens the end lender's incentive to produce information, but strengthens I's incentive. Indeed, the correlation that balances these two forces and maximizes credit capacity is $\phi = 1/2$, i.e., when the two firms are uncorrelated—conditional on one firm's failure, the failure or success probability of the other firm is 50%. When we extend the network to include more than one intermediary, we will expand on the intuition that widening the funding bottleneck requires equalizing the joint probabilities along the intermediation chain.

Proposition 2 (Intermediated financing capacity) *The borrowing capacity of intermediated fi-*

nancing through rehypothecation is given by (27), which is greater than that of direct financing given by (20). Furthermore, intermediated financing capacity is maximized when project outcome is uncorrelated between the two firms, i.e., $\phi = 1/2$.

Importantly, I serving as an intermediary does not impact its capacity to raise funds for its own liquidity needs. In fact, if I is also hit by the liquidity shock, it can raise direct financing from the end lender or pursue indirect financing with F serving as an intermediary. This creates a network of intermediation chains weaved together and intersecting one another that seems spurious but is, in fact, critical for sustaining greater borrowing capacities for all the end borrowers by diluting the chain participants agents' incentives for costly information acquisition.

3.2 Specialized Intermediaries

In this subsection, we consider firms' investment decisions at $t = 0$. So far, we have only allowed firms to invest their endowment K into projects with uncertain pledgeable (liquidation) value, and stochastic nonpledgeable profits. Next, we extend our model by allowing firms to alternatively invest in risk-free (government) bonds. Each unit of bond purchased at $t = 0$ pays one unit of goods at $t = 2$. We assume that the supply of government bonds is perfectly elastic at a price equal to one. Thus, the bond price is one at $t = 1$.

A firm invests in the project if the project return is greater than the bond return, denoted by r^b. One would expect r^b to be equal to one since the bond price is equal to one at $t = 0$ and 1, and its terminal payoff at $t = 2$ is also one unit of goods. This argument ignores that a firm's bond holdings may facilitate intermediation.

We assume a firm holding bonds faces a cost of acquiring information on the other firm's project that is equal to $\bar{C} > C$. Intuitively, by specializing in bond investments, the firm relinquishes expertise about projects. In contrast, the generic investor, whose information cost is C, may have exposure to more broad asset classes and thus has a stronger expertise. A firm specializing in bonds can be viewed as a money market fund that specializes in relatively safe fixed-income securities and intermediates funds, while a generic investor can be a universal bank, an asset management firm, or other investors that have research capacity in not only safe bonds but also riskier assets and projects. Therefore, choosing to invest in the bond (or to be "narrow") is to stay ignorant, and we will show that by raising its own information acquisition cost, the firm can channel more funds from the investor to the other firm.

First, we compute a firm's return from investing in a project, denoted by v^i per unit of initial investment. Total expected payoff of a project is given by

$$V^i \equiv v^i K = \underbrace{(1-\lambda)\left[(1-q)AK + \bar{U}\right]}_{\textit{no liquidity needs}} + \underbrace{\lambda(1-q)(AL^i - R^i + \bar{U})}_{\textit{liquidity event \& success}} + \underbrace{\lambda q(1-x^i)\bar{U}}_{\textit{liquidity event \& failure}}. \tag{29}$$

As previously discussed, $x^i = R^i/\bar{U}$ (see (16)) and $R^i = L^i$ (see (17)), the expression simplifies:

$$V^i = \left[(1-\lambda)(1-q)A + \bar{u}\right] K + \lambda\left[(1-q)A - 1\right] L^i, \tag{30}$$

where we define $\bar{u} = \bar{U}/K$. When we eliminate the liquidity shock, i.e., under $\lambda = 0$, the project delivers an expected return equal to $(1-q)A + \bar{u}$, i.e., the sum of a baseline return $\bar{u}$ and an additional return A if the project is successful with probability $1-q$, as shown in Figure 1. If the firm is hit by a liquidity shock, the liquidation value of the project is intact, but to achieve the additional return, the firm must make an additional investment L^i at $t = 1$.

As we have demonstrated, intermediated financing dominates direct financing by diluting the incentive to produce costly information. Therefore, we consider L^i, given by (27) under intermediated financing. As a reminder, the attributes of the collateral or pledgeable value are summarized in $\Gamma = \left[p\left(\frac{G-\bar{U}}{\bar{U}}\right)\right]^{-1}$ (see the definition (7)) and the expected value is $\bar{U}$. Let $\ell^i = L^i/\bar{U}$, i.e.,

$$\ell^i = \min\left\{1,\ \left[p\left(\frac{G-\bar{U}}{C}\right)\hat{q}\right]^{-1}\right\} = \min\left\{1,\ \left[p\left(\frac{G-\bar{U}}{C}\right)\max\{q\phi,\ q(1-\phi)\}\right]^{-1}\right\}. \tag{31}$$

The project value can now be solved as a function of primitive parameters,

$$v^i = \bar{u} + (1-\lambda)(1-q)A + \lambda\left[(1-q)A - 1\right]\ell^i\bar{u}. \tag{32}$$

Similarly, we can compute the project's return when financing is not intermediated, which we denote by w^i (such as total payoffs in this case is $W^i = w^i K$).

Define $\underline{\ell}^i = L^i/\bar{U}$ (where L^i is given by (20)), i.e.,

$$\underline{\ell}^i = \min\left\{1,\ \left[p\left(\frac{G-\bar{U}}{C}\right)q\right]^{-1}\right\}, \tag{33}$$

The project return with direct financing is given by

$$w^i = \bar{u} + (1-\lambda)(1-q)A + \lambda\left[(1-q)A - 1\right]\underline{\ell}^i\bar{u}. \tag{34}$$

If the intermediary invests in a bond, the alternatives for F, upon a liquidity shock, is to seek financing directly from the deep-pocket investor (which we denote by d for direct financing) or through the intermediary invested in bonds The amount of direct financing raised by issuing information-insensitive debt is given by (20)

$$L_F^{i,d} = \min\left\{\bar{U},\ \Gamma\frac{C}{q}\right\}, \tag{35}$$

In the other case, when raising funds from the end lender, I pledges its bond holdings worth K ($\geq \bar{U}$) as collateral.[11] When lending to F under the information-insensitive debt contract, firm I can lend up to $\min\left\{\bar{U}, \Gamma\bar{C}/q\right\}$, where C in the solution given by (20) is replaced by $\bar{C}$. Therefore, by investing in the bond instead of a project, I chooses to stay uninformed, facing a higher information cost, and thereby can lend more to F. The amount of funding for F is

$$L_F^{i,I} = \min\left\{\bar{U},\ \Gamma\frac{\bar{C}}{q}\right\}, \tag{36}$$

where the additional superscript "I" represents funding channeled by I.

If $L_F^{i,d} > L_F^{i,I}$, funding intermediation by I does not add value, and therefore, it does not contribute to the return on I's bond investment, which then implies that $r^b = 1$. In this case, as

[11]Note that, equivalently, I could also sell the bond to the investor in exchange for funding rather than pledge it as collateral and borrow from the investor. Distinguishing selling the bond and pledging as collateral to borrow is not the focus of our paper and has been studied in the literature (e.g., Parlatore (2019)).

long as the return on investing in a project is greater than one, I would not invest in the bond at $t = 0$. Note that the comparison is between $r^b = 1$ and project return $R = v^i$ (rather than $R = w^i$) because, given that F invests in the project, once I invests in the project as well, the two firms can engage in funding intermediation for each other as described in Section 3 to enlarge financing capacity (rather than pursue direct financing that leads to a project's return $R = w^i$).

Therefore, for I to invest in bond, we must have $L_F^{i,d} < L_F^{i,I}$. Assuming both IC constraints bind, we have $L_F^{i,I} = \Gamma\frac{\bar{C}}{q} > \Gamma\frac{C}{q} = L_F^{i,d}$, that is I's funding intermediation adds value because $\bar{C} > C$. By investing in the bond rather than the project and staying uninformed, I can channel more funds to F by raising its own information production cost.

The surplus from increasing F's funding capacity through I's intermediation (scaled by firm I's bond investment K) is given by

$$s^b := \lambda[(1-q)A - 1]\Gamma\left(\frac{\bar{C} - C}{qK}\right) = \lambda\left[\frac{\bar{C} - C}{p\left(G - \bar{U}\right)q}\right][(1-q)A - 1]\bar{u}, \tag{37}$$

where the superscript "b" represents funding intermediation facilitated by I bonds instead of investing in the project. Recall that $(1-q)A - 1$ is the expected net return at $t = 1$ (if the project succeeds, which happens with probability $(1-q)$, one unit of goods invested generates A).

If a fraction h of the surplus is captured by I, the funding intermediary, then I's total (gross) return on bond holding is

$$r^b = 1 + hs^b. \tag{38}$$

With probability λ, F has liquidity needs at $t = 1$, and I earns h fraction of the surplus created from enlarging F's financing capacity (relative to F's outside option of direct financing).[12] The return on F's investment in the project is equal to the return from direct financing at $t = 1$, w^i, plus the $(1-h)$ fraction of value created by moving from direct to intermediated financing:

$$R = w^i + (1-h)s^b. \tag{39}$$

[12] In Section 3, the surplus created by indirect financing relative to direct financing goes to the ultimate borrower. Here we consider a more general case where the surplus can be split between the borrower and funding intermediary.

In equilibrium, both firms should be indifferent between investing in the bond and investing in a project, i.e., $r^b = R$, or equivalently,

$$h = \frac{1}{2} + \left(\frac{w^i - 1}{2s^b}\right), \tag{40}$$

where w^i is given by (34) and s^b is given by (37). Under $w^i > 1$ as shown in (34), the funding intermediary takes a larger fraction of the surplus from indirect financing than the ultimate borrower, i.e., $h > 1/2$. Moreover, for the equilibrium to exist, the bond return must be sufficiently high such that F does not deviate from the bond investment to the project investment for a return equal to v^i (i.e., the return from investing in projects when both firms invest in projects and intermediate indirect financing for one another as characterized in Section 3). The condition to prevent such deviation is $r^b > v^i$, or equivalently,

$$h > \frac{v^i - 1}{s^b}. \tag{41}$$

where v^i is defined in (32). Finally, we verify that given that I invests in the bond, F does not have an incentive to deviate. This is obvious because if F deviates, both firms would invest in the bond and there would be no need for funding intermediation, which then implies $r^b = 1$.

The equilibrium with one firm investing in the bond and the other in a project dominates the equilibrium in Section 3 where both firms invest in projects and intermediate funding supply for one another if the following condition holds,

$$1 + s^b + w^i > 2v^i. \tag{42}$$

Proposition 3 (Intermediated financing facilitated by bond) *The equilibrium with one firm investing in the bond and the other in a project exists with h given by (40) if the condition (41) holds. If the condition (42) holds, it dominates the equilibrium where both firms invest in projects.*

In summary, the bond plays two roles. First, when the intermediary firm raises funds from the end lender, pledging the bond as collateral does not induce costly information production by the end lender and thereby allows a frictionless channeling of funds. Second, when the intermediary lends to the ultimate borrower, holding the bond allows the intermediary to stay uninformed about the borrower's project by raising the cost of information production. As a result of these two forces, the equilibrium with only one firm investing in a project (with the other investing in the bond) can dominate that where both firms invest in projects and intermediate funding for one another.

4 Intermediation Networks

Intermediation emerges endogenously in the presence of two firms, with one firm as the ultimate borrower and the other as an intermediary. If we introduce a third firm as another intermediary, the end lender's incentive to produce information can be further diluted since the probability of receiving the collateral from the ultimate borrower is the joint probability of the firm and all intermediaries defaulting. Since many firms can borrow and at the same time serve as intermediaries, there may exist several intermediation chains that combine to form an intermediation network. The network is then characterized by a seemingly spurious flow of funds between financial intermediaries that make distinct investments in their projects but also channel funds to one another, being the ultimate borrowers and intermediate lenders on several chains at the same time.

Involving many firms in intermediation dilutes each funding provider's "share" of the collateral asset along the chain: each participant on the chain only owns the collateral asset with a small probability, so the incentive to produce costly information is weak. Such informational diversification is across lenders along the intermediation chain rather than projects. It is the expected value of one project's collateral that is probabilistically split along the intermediation chain. Next, we characterize the optimal chain length and the optimal allocation of intermediaries within the chain.

4.1 Optimal Chain Length

Let F denote the ultimate borrower. We use numbers to represent the intermediaries between F and the ultimate lender. Take an intermediary located at position i, and let γ^{i-1} denote the joint probability that F defaults and all the previous i intermediaries in the chain default, with the initial condition $\gamma^F = q$. Let ϕ_1^F denote Intermediary 1's default probability conditional on F's

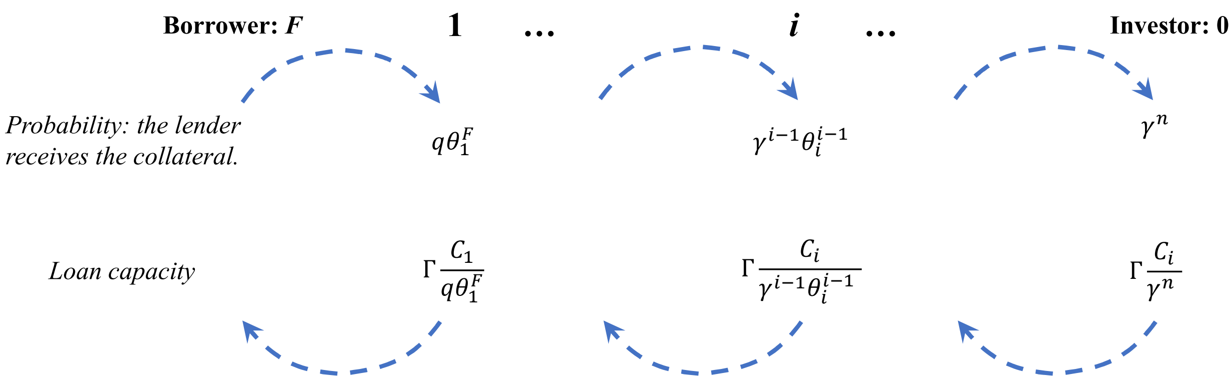

Figure 3: **A Chain with n Intermediaries.**

default. Let ϕ_2^1 denote Intermediary 2's default probability conditional on the joint event of F's default and Intermediary 1's default. In general, ϕ_i^{i-1} is the probability of the i-th intermediary's default conditional on the default of F' and all the preceding $i-1$ intermediaries default. Let $\theta_i^{i-1} = 1 - \phi_i^{i-1}$ denote the probability of i-th intermediary's survival conditional on F's default and all the preceding $i-1$ intermediaries' default. We introduce separate notation to better present the intuition in our analysis later. Let C_i denote the i-th intermediary's information cost. For tractability, we denote the end lender as intermediary 0, hence C_0 is this lender's information cost. Figure 3 provides a representation of a chain with n intermediaries based on this notation.

In the following, we characterize the endogenous formulation of an intermediation chain. The funding capacity of direct financing without involving any intermediary is given by $\Gamma C_0/\gamma^F$.

The first intermediary is chosen to intermediate between F and the ultimate lender, denoted by "0" from now on. For example, the intermediary may achieve the largest increase in financing capacity, i.e., $\Gamma \min\left\{\frac{C_1}{\gamma^F\theta_1^F}, \frac{C_0}{\gamma^F\phi_1^F}\right\} - \Gamma\frac{C_0}{\gamma^F}$. is maximized. Note that this is unlikely to be optimal as the first intermediary affects whether future intermediaries will be included and their conditional default or survival probabilities, that is, their probability of receiving F's collateral and incentive to produce costly information.

In the following, we characterize the necessary condition for an intermediary to be included when an intermediation chain is extended, and then we proceed to characterize how the optimal chain is formed to maximize F's financing capacity.

Starting with the shortest intermediation chain (F, 1, 0), including the second intermediary enlarges financing capacity if

$$\Gamma \min\left\{\frac{C_1}{\gamma^F\theta_1^F}, \frac{C_2}{\gamma^F\phi_1^F\theta_2^1}, \frac{C_0}{\gamma^F\phi_1^F\phi_2^1}, \bar{U}\right\} > \Gamma \min\left\{\frac{C_1}{\gamma^F\theta_1^F}, \frac{C_0}{\gamma^F\phi_1^F}, \frac{\bar{U}}{\Gamma}\right\},$$

where the left side is the financing capacity of the extended chain, (F, 1, 2, 0), and the right side is the financing capacity of the initial chain, (F, 1, 0).

First, it is clear that if $\bar{U} < \Gamma \min\left\{\frac{C_1}{\gamma^F\theta_1^F}, \frac{C_0}{\gamma^F\phi_1^F}\right\}$, that is the shortest chain, (F, 1, 0), has already maximized financing capacity to the fully pledgeable value, adding a new intermediary is unnecessary. If this condition does not hold, there are two scenarios when introducing the second intermediary, inserting 2 between F and 1 or between 1 and 0. The key is to identify the bottleneck, that is which is smaller, the funding capacity of edge (F, 1), $\frac{C_1}{\gamma^F\theta_1^F}$, or the funding capacity of edge (1, 0), $\frac{C_0}{\gamma^F\phi_1^F}$. For example, consider the bottleneck being (F,1), then the third term in $\min\left\{\frac{C_1}{\gamma^F\theta_1^F}, \frac{C_2}{\gamma^F\phi_1^F\theta_2^1}, \frac{C_0}{\gamma^F\phi_1^F\phi_2^1}\right\}$ is irrelevant, because $C_1/C_0 < \theta_1^F/\phi_1^F$ implies that the first term is smaller than or equal to the third term given $\phi_2^1 \in [0,1]$, i.e., $\frac{C_1}{\gamma^F\theta_1^F} < \frac{C_0}{\gamma^F\phi_1^F}$ implies $\frac{C_1}{\gamma^F\theta_1^F} < \frac{C_0}{\gamma^F\phi_1^F\phi_2^1}$. Therefore, the relevant comparison is between $\min\left\{\frac{C_1}{\gamma^F\theta_1^F}, \frac{C_2}{\gamma^F\phi_1^F\theta_2^1}\right\}$ and $\frac{C_1}{\gamma^F\theta_1^F}$. Clearly, $\min\left\{\frac{C_1}{\gamma^F\theta_1^F}, \frac{C_2}{\gamma^F\phi_1^F\theta_2^1}\right\} \leq \frac{C_1}{\gamma^F\theta_1^F}$, so inserting Intermediary 2 to (1, 0) rather than the bottleneck (F, 1) does not enlarge the financing capacity.

Proposition 4 (Bottleneck identification) *If the current intermediation chain has not maximized financing capacity to the full pledgeable value $\bar{U}$, then when extending the chain, the new intermediary is inserted into the edge with smallest funding capacity.*

We have shown that the first step of extending an intermediation chain and including a new intermediary is to identify the bottleneck. The next question is what criteria should the new intermediary meet for F's financing capacity to be enlarged? We characterize a necessary and sufficient condition that reveals sharply the key economic intuition of our model.

Consider the bottleneck of chain (F, 1, 0) being (1, 0), i.e., $\min\left\{\frac{C_1}{\gamma^F\theta_1^F}, \frac{C_0}{\gamma^F\phi_1^F}\right\} = \frac{C_0}{\gamma^F\phi_1^F} < \frac{C_1}{\gamma^F\theta_1^F}$. Inserting Intermediary 2 to form (1, 2, 0) enlarges financing capacity if and only if

$$\min\left\{\frac{C_2}{\gamma^F\phi_1^F\theta_1^F}, \frac{C_0}{\gamma^F\phi_1^F\phi_2^1}\right\} > \frac{C_0}{\gamma^F\phi_1^F}.$$

Given that $\frac{C_0}{\gamma^F\phi_1^F\phi_2^1} > \frac{C_0}{\gamma^F\phi_1^F}$ under $\phi_2^1 \in (0, 1)$, inserting Intermediary 2 to extend the edge from (1, 0) to (1, 2, 0) enlarges financing capacity if and only if $\frac{C_2}{\gamma^F\phi_1^F\theta_2^1} > \frac{C_0}{\gamma^F\phi_1^F}$, or equivalently,

$$\frac{C_2}{\theta_2^1} > C_0. \tag{43}$$

Intuitively, θ_2^1 is the probability that both F and Intermediary 1 default but Intermediary 2 survives and ends up holding the collateral. If $C_2 > C_0$, this inequality holds obviously; if not, this new intermediary's information cost scaled by the probability of it receiving the collateral must be sufficiently large relative to that of the ultimate investor's information cost.

Consider the decision to insert the n-th intermediary. First, we identify the bottleneck being (i,i+1), where $i \in \{F, 1, ..., n-1\}$ with the convention $F + 1$ is 1 and $(n-1)+1$ is the index for the ultimate investor. Next, we show that the n-th intermediary enlarges financing capacity by extending the edge (i,i+1) to two edges (i,n,i+1) if and only if

$$\frac{C_n}{\theta_n^i} > \frac{C_{i+1}}{\theta_{i+1}^i},$$

where θ_n^i is the probability of the newly inserted intermediary's survival conditional on F's default and the default of all the intermediaries from 1 to i and θ_{i+1}^i is the probability of Intermediary $i+1$'s survival conditional on F's default and the default of all the intermediaries from 1 to i. This condition nests (43) as the conditional survival probability of the investor is equal to 1 ($\theta_0^1 = 1$).

Inserting the n-th intermediary between i and i+1 enlarges financing capacity if and only if

$$\Gamma \min \left\{ \frac{C_1}{\gamma^F \theta_1^F}, \frac{C_2}{\gamma^1 \theta_2^1}, ..., \frac{C_i}{\gamma^{i-1} \theta_i^{i-1}}, \frac{C_n}{\gamma^i \theta_n^i}, \frac{C_{i+1}}{\gamma^i \phi_n^i \hat{\theta}_{i+1}^i}, ..., \frac{C_{n-1}}{\hat{\gamma}^{n-2} \hat{\theta}_{n-1}^{n-2}}, \frac{C_0}{\hat{\gamma}^{n-1} \hat{\phi}_n^{n-1}} \right\} >$$
$$\Gamma \min \left\{ \frac{C_1}{\gamma^F \theta_1^F}, \frac{C_2}{\gamma^1 \theta_2^1}, ..., \frac{C_i}{\gamma^{i-1} \theta_i^{i-1}}, \quad \frac{C_{i+1}}{\gamma^i \theta_{i+1}^i}, \quad ..., \quad \frac{C_{n-1}}{\gamma^{n-2} \theta_{n-1}^{n-2}}, \frac{C_0}{\gamma^{n-1} \phi_n^{n-1}} \right\}$$

where $\hat{\gamma}^i$ represents the joint probability of F's default, the first i intermediaries' default, *and* the new intermediary's default, $\hat{\phi}_{i+1}^i$ is the probability of Intermediary i+1's default conditional on F's default, the first i intermediaries' default, *and* the newly inserted intermediary's default, and $\hat{\phi}_{i+1}^i$ is the probability of Intermediary i+1's survival conditional on F's default, the first i intermediaries' default, *and* the newly inserted intermediary's default. As a reminder of our notation, we have, by definition, $\gamma^{n-1}\phi_n^{n-1} = \gamma^n$ and $\hat{\gamma}^{n-1}\hat{\phi}_n^{n-1} = \hat{\gamma}^n$.

This condition is essentially an IC constraint for the network to expand because we need the total surplus for those already on the chain to improve. An important insight is that inserting a new intermediary changes these probabilities for those "downstream" in the chain, but not "upstream." Since the left and right sides share the initial i items, the condition is equivalent to

$$\Gamma \min \left\{ \frac{C_n}{\gamma^i \theta_n^i}, \frac{C_{i+1}}{\gamma^i \phi_n^i \hat{\theta}_{i+1}^i}, ..., \frac{C_{n-1}}{\hat{\gamma}^{n-2} \hat{\theta}_{n-1}^{n-2}}, \frac{C_0}{\hat{\gamma}^{n-1} \hat{\phi}_n^{n-1}} \right\} > \Gamma \min \left\{ \frac{C_{i+1}}{\gamma^i \theta_{i+1}^i}, ..., \frac{C_{n-1}}{\gamma^{n-2} \theta_{n-1}^{n-2}}, \frac{C_0}{\gamma^{n-1} \phi_n^{n-1}} \right\}. \tag{44}$$

Note that, for any $k \in \{1, ..., n-(i+1)\}$, we have, by the definitions of probabilities,

$$\frac{C_{n-k}}{\hat{\gamma}^{n-k-1} \hat{\theta}_{n-k}^{n-k-1}} > \frac{C_{n-k}}{\gamma^{n-k-1} \theta_{n-k}^{n-k-1}},$$

because the events measured by $\hat{\gamma}_{n-k}^{n-k-1}$ contains one more event (the new intermediary's default) than the events measured by γ_{n-k}^{n-k-1} so $\hat{\gamma}_{n-k}^{n-k-1} \leq \gamma_{n-k}^{n-k-1}$. Next, we impose the following assumption:

$$\hat{\theta}_{n-k}^{n-k-1} \leq \theta_{n-k}^{n-k-1}. \tag{45}$$

The probability for Intermediary n-k to survive is lower when another intermediary (the new one) defaults. By definition, $\hat{\theta}_{n-k}^{n-k-1}$ measures the probability of survival conditional on all the preceding $n-k-1$ intermediaries' default *and* the new intermediary's default, while θ_{n-k}^{n-k-1} measures the probability of survival conditional on only the previous $n-k-1$ intermediaries' default.

An interesting property emerges: when a new intermediary is inserted into the chain, both γ and θ decrease. The former is lower because it is a joint probability and, from γ to $\hat{\gamma}$, another event is added (the new intermediary's default). The latter is lower as it is a conditional probability of survival, so according to our assumption, when more intermediaries default (i.e., adding the new intermediary's default), the economic environment is likely worse, so θ declines to $\hat{\theta}$.

Therefore, in the condition for the newly inserted intermediary to enlarge financing capacity, i.e., the inequality (44), from the third terms on the left side to the last term, they are all larger than the corresponding terms on the right side (i.e., the second to the last terms). Moreover, since the edge (i, i+1) is the bottleneck before we insert the n-th intermediary, we know that the right side can be simplified to just $\frac{C_{i+1}}{\gamma^i \theta_{i+1}^i}$. On the left side, we can ignore the third to last terms as they are larger than the second to last terms on the right side. So, the condition (44) can be simplified to

$$\min\left\{\frac{C_n}{\gamma^i \theta_n^i}, \frac{C_{i+1}}{\gamma^i \phi_n^i \hat{\theta}_{i+1}^i}\right\} > \frac{C_{i+1}}{\gamma^i \theta_{i+1}^i}, \tag{46}$$

where we also divide both sides by Γ. Note that $\frac{C_{i+1}}{\gamma^i \phi_n^i \hat{\theta}_{i+1}^i} \geq \frac{C_{i+1}}{\gamma^i \theta_{i+1}^i}$ because $\phi_n^i \in [0,1]$. Therefore, for the inequality to hold, we only need

$$\frac{C_n}{\theta_n^i} > \frac{C_{i+1}}{\theta_{i+1}^i}, \tag{47}$$

where, to simplify the expression, we divide both sides by γ^i. A special case is that when all have the same θ and the same C, this condition implies that only one intermediary will be inserted between F and the end lender, as the first intermediary is always the bottleneck.

Every time the chain is extended the condition (47) must be satisfied so that the total surplus is increased and the existing participants on the chain are willing to accept the new intermediary to join. For now, we do not specify how the surplus is split. After this new intermediary is added, the chain now has F, the n intermediaries, and the end lender. The intermediaries are relabeled from the one closest to F as 1 to the one closet to the end lender as n. In the previous example, the labels of the first i intermediaries do not change, the newly added intermediary becomes Intermediary i+1, and the other existing intermediaries' labels are plus one. Then, if the chain has not maximized financing capacity to the full pledgeable value $\bar{U}$, it can be further extended provided that a new intermediary meeting the criterion (47) can be found.

Proposition 5 (Chain extension) *If the current intermediation chain with n-1 intermediaries has not maximized financing capacity to the full pledgeable value $\bar{U}$, the addition of the n-th intermediary to the bottleneck (i, i+1), where $i \leq n-1$, satisfies the condition (47).*

Therefore, we have shown that the n-th intermediary is added only if an intermediary that satisfies the condition (47) can be found, where the right side is given by the bottleneck (i, i+1) of the current chain. Our proof shows that an intermediation chain can be formed recursively, starting from inserting the first intermediary and ending when no intermediary can be found to satisfy the condition (47) or when the current chain has maximized financing capacity to the full pledgeable value, $\bar{U}$. Thus, the condition (47) is about the length of the chain.

4.2 Optimal Intermediary Sequencing

In the following, we assume that the chain does not maximize financing capacity to the full pledgeable value, $\bar{U}$, so whether to extend the chain depends on whether intermediaries that satisfy the condition (47) can be found. When multiple intermediaries satisfy this condition, which one to include remains an open question. Inserting an intermediary affects whether and which intermediaries will be included afterward. A local optimum may not be the global optimum. More generally, how should intermediaries be positioned on the chain to maximize the financing capacity?

To tightly characterize the optimal chain and demonstrate the key economic forces, we consider a simplified setting with conditionally independent intermediaries: Intermediary k's probability of survival conditional on F's default, $\theta(k)$, is a univariate function of its index k, and

$$\theta(k) = \mathbf{Prob}(survival|F\text{'s default}) = \mathbf{Prob}(survival|F\text{'s default \& any intermediaries' default}).$$

Conditional on F's default, intermediaries have different default probabilities but their default is independent. This is consistent with the more general assumption (45). Note that the index k is assigned to differentiate intermediaries, and this index may differ from the intermediaries' ranking on the chain (i.e., how close they are to F), which can change when more intermediaries are added. Intermediaries also differ in information cost. Let $C(k)$ denote intermediary k's information cost.

When intermediary k is the i+1-th intermediary, the financing capacity of the edge (i, i+1) is $\Gamma\frac{C(k)}{\gamma^i\theta(k)}$. Because the bottleneck of a chain determines its financing capacity, the optimal chain should order intermediaries such that $\Gamma\frac{C(k)}{\gamma^i\theta(k)}$ is equalized along the chain. The intuition is similar to production maximization under a Leontief production function. Note that ordering intermediaries affects γ^i. Therefore, baring any integer constraint, the optimal chain should feature

$$\frac{C(k)}{\gamma^{i(k)}\theta(k)} = \frac{C(k')}{\gamma^{i(k')}\theta(k')}, \tag{48}$$

where $i(\cdot)$ is the ordering function with, for example $i(k) = 2$ meaning that intermediary k is the second intermediary (i.e., the third participant on the chain). Rearranging the equation, we obtain

$$\frac{\gamma^{i(k)}}{\gamma^{i(k')}} = \frac{C(k)/\theta(k)}{C(k')/\theta(k')}. \tag{49}$$

Therefore, we conclude that, for an intermediary with a lower $C(k)/\theta(k)$, its $\gamma^{i(k)}$ should be lower.

Proposition 6 (Intermediary sequencing condition) *The optimal sequencing of intermediaries, i.e., the intermediary-ordering function $i(\cdot)$, satisfies the condition (49).*

Intuitively, two intermediaries may have the same incentives to acquire information despite different information costs. Intermediaries with a high information costs can face a high probability of ending up with the collateral without triggering information acquisition. The same is the case for an intermediary with low information costs but low probability of ending up with the collateral.

Special case: Only heterogeneity on information costs. Consider the special case of all intermediaries having the same survival probability, i.e., $\theta(k) = \theta \in (0, 1)$ for all k, which then implies that $\gamma^{i(k)} = q(1-\theta)^{i(k)-1}$. Therefore, the condition (49) above can be simplified to

$$\frac{(1-\theta)^{i(k)-1}}{(1-\theta)^{i(k')-1}} = \frac{C(k)}{C(k')}. \tag{50}$$

Taking logarithm on both sides, we obtain

$$i(k) - i(k') = \frac{\ln C(k) - \ln C(k')}{\ln(1-\theta)}. \tag{51}$$

Note that $\ln(1-\theta) < 0$ because $\theta \in (0, 1)$. Therefore, we arrive at the following corollary: for intermediaries with low information costs, the probability of it receiving the collateral—the joint probability of F's default and all preceding intermediaries' default, $\gamma^{i(k)}$—should be sufficiently low to dampen the incentive of information production.

Corollary 1 (Optimal sequencing under homogeneous θ) *Under $\theta(k) = \theta \in (0, 1)$, an intermediary k with a lower information cost is placed later in the optimal chain, i.e., $i(k)$ is higher.*

Special case: Only heterogeneity on correlation with the borrower. Next, we consider another simplified setting. Instead of heterogeneous $C(k)$ and homogeneous θ, we consider the same C and heterogeneous $\theta(k)$, hence heterogeneous conditional default probability, $\phi(k)$.

For any k and k', the "Leontief" condition can be simplified to:

$$\gamma^{i(k)}\theta(k) = \gamma^{i(k')}\theta(k'). \tag{52}$$

Note that $\gamma^{i(k)} = q \prod_{i(j)<i(k)} \phi(j)$, where, as previously discussed, $i(\cdot)$ is the ordering function, and $\prod_{i(j)<i(k)} \phi(j)$ is the joint probability of all intermediaries between B and $i(k)$ defaulting conditional on F's default. Therefore, the condition can be simplified to

$$\prod_{i(j)<i(k)} \phi(j)\theta(k) = \prod_{i(j)<i(k')} \phi(j)\theta(k'). \tag{53}$$

Let $\underline{i}(k,k') = \min\{i(k), i(k')\}$, which is a function derived from the ordering function $i(\cdot)$. If, for instance, $i(k') = \underline{i}(k,k')$, then the condition can be further simplified to

$$\theta(k) = \prod_{i(k)\leq i(j)<i(k')} \phi(j)\theta(k') < \theta(k'), \tag{54}$$

as $\prod_{i(k)\leq i(j)<i(k')} < 1$. Therefore, the conclusion we draw is that intermediaries with lower survival probability conditional on F's default precede those with higher probability on the optimal chain.

Corollary 2 (Optimal sequencing under homogeneous C) *Under $C(k) = C$, an intermediary k with a higher conditional (on F's default) survival probability, $\theta(k)$, is placed later in the optimal chain, i.e., $i(k)$ is higher.*

Intuitively, the optimal chain pushes intermediaries with high survival probabilities downstream, closer to the end lender, so that the probability for it to end up with the collateral—the joint probability of F's default and all the preceding intermediaries' default—is low and can counteract its (high) conditional survival probabilities. Doing so evenly distributes the force of probability dilution along the chain, in line with the "Leontief" condition (48), so that each chain participant's share of the collateral is low in expectation and each participant's incentive to produce information is equally weak, avoiding a bottleneck on the chain.

4.3 Endogenous Chain Formation

We characterize the endogenous formation of intermediation chains. To form the optimal chain, intermediaries are added one after another in a laissez-faire environment, and each step of chain extension must satisfy the condition (47) so that the financing capacity of the chain is increased and there is economic surplus created for all existing participants to share. In a way, the condition (47) is an incentive-comparability constraint for all existing chain participants to accept a new intermediary. In the following, we consider the simplified setting of conditionally independent intermediaries and, specifically, the case of homogeneous θ and the case of homogeneous $C(k)$.

Homogeneous conditional survival probability. When every intermediary has the same conditional (on F's default) survival probability, $\theta(k) = \theta$, the condition (47) for including the n-th intermediary on an existing chain with bottleneck (i, i+1) can be simplified to

$$\frac{C_n}{\theta_n^i} > \frac{C_{i+1}}{\theta_{i+1}^i} \;\; \Leftrightarrow \;\; C_n > C_{i+1}, \tag{55}$$

where C_n is the information cost of the n-th intermediary being added to the chain and C_{i+1} is the information cost of the lender of the current bottleneck (i,i+1).

Optimal intermediation emerges in a laissez-faire environment as follows. Starting from (F, 0), intermediaries are added to the chain one by one, from the intermediary with the lowest information cost to the one with the highest information cost. Every time a new intermediary is added, the IC constraint $C_n > C_{i+1}$, i.e., the condition (56), is satisfied. And, every time when the chain is extended, the bottleneck is between F and the first intermediary, and recursively, as intermediaries with higher information costs are added, the bottleneck is widened. The resultant chain features intermediaries with higher information costs preceding those with lower information costs in line with the condition (51) for optimal intermediary sequencing.

Corollary 3 (Chain formation under homogeneous θ) *Under $\theta(k) = \theta \in (0, 1)$, intermediaries are added sequentially onto the chain, starting from the one with the lowest information cost, and after introducing the first intermediary, every new intermediary is inserted into the edge (F, 1).*

Homogeneous information cost. Next, we consider the other special case where $C(k) = C$ for all k. Let (i, i+1) be the bottleneck on the existing chain of n-1 intermediaries, and consider the addition of the n-th intermediary. The condition (47) can be simplified to

$$\frac{C_n}{\theta_n^i} > \frac{C_{i+1}}{\theta_{i+1}^i} \;\; \Leftrightarrow \;\; \theta_n^i < \theta_{i+1}^i, \tag{56}$$

where θ_n^i is the conditional (on F's default) survival probability of the n-th intermediary being added to the chain and θ_{i+1}^i is the conditional survival probability of the i+1-th intermediary on the current chain. Therefore, the newly added intermediary should have smaller survival probability than the existing intermediary that will be placed after it on the extended chain.

Therefore, the chain can be formed endogenously as follows. Starting from (F, 0), intermediaries are added to the chain one by one from the intermediary with the highest conditional survival probability to the one with the lowest conditional survival probability. Every time a new intermediary is added, the IC constraint $\theta_n^i < \theta_{i+1}^i$, i.e., the condition (56), is satisfied. And, every time when the chain is extended, the bottleneck is between F and the first intermediary so that, recursively, as intermediaries with lower conditional survival probabilities are added, the bottleneck is widened. The resultant chain features intermediaries with lower conditional (on F's default) survival probability preceding those with higher conditional survival probability in line with the condition (54) for optimal intermediary sequencing.

Corollary 4 (Chain formation under homogeneous C) *Under $C(k) = C$, intermediaries are added sequentially onto the chain, starting from the one with the highest survival probability conditional on F's default, and after introducing the first intermediary, every new intermediary is inserted into the edge (F, 1).*

Intuitively, the intermediaries with lower conditional survival probabilities are placed closer to the ultimate borrower, because, even though the probability for collateral to reach them—the joint probability of F's default and all preceding intermediaries' default—is higher, their survival probability is low. Such balance equalizes along the chain or smooths out the probability of each intermediary receiving the collateral (rather than passing it along to the next chain participant), in line with the general condition (48) for avoiding bottlenecks and maximizing funding capacity.

5 Conclusions

A lender is willing to "lend in the dark" when the likelihood of ending up with the asset is low. While a lender ends up owning the asset only when the borrower defaults, an equity investor always owns it. Since producing information is more beneficial when the likelihood of owning the asset increases, an equity investor has a stronger incentive to produce information than a debt investor. Therefore, when information production is costly, information-insensitive contracts are preferred, and among those debt generates a greater financing capacity. Hence, in the pecking order of financing instruments, information-insensitive debt tends to be at the top.

Intermediation networks arise endogenously because they can dilute the incentives to produce information even further. This happens because the joint probability of the end borrower and all the preceding lenders' defaulting is smaller than the single probability of the borrower's default, so the incentive to produce information is reduced. This is, credit channeled through seemingly spurious and unnecessary chains of intermediation is larger than with direct financing. This role of intermediation may induce certain firms to specialize in obtaining assets, such as government bonds, that in principle have lower returns but are valuable to serve as intermediary to "grease" the flow of credit within the chain. We have also characterized the anatomy of this information-concealing credit architecture. We show that the length of intermediation chains and the sequencing of intermediaries within the chain is optimal and depends on the correlation structure of intermediaries' asset correlations and their information acquisition costs.

Our model can be applied to understand various forms of debt contracts and intermediation, for example, repurchase agreements (repo) and rehypothecation. Repo contracts require the borrower's asset to be transferred to the lender on the spot and transferred back when the debt is repaid, while other debt contracts channel funds to the borrower on the spot and only transfer the asset in bankruptcy. The timing of collateral transfer is inconsequential in our model. When applying our model to repo, requiring the backing asset to be transferred on the spot, in which case the intermediary channels both funds and collateral, is only for interpreting the intermediated credit flow as repo and collateral intermediation (rehypothecation). Our model shows that a repo chain, including the end borrower, an intermediary, and the end lender, distributes the probability of asset possession between the intermediate and end lenders. Therefore, repo chains and collateral rehypothecation are mechanisms for diluting lenders' incentives to produce costly information.

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