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Incentives to innovate and financial crises ☆

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ABSTRACT

In this paper I develop a model of a competitive financial system with unrestricted but costly entry and an endogenously determined number of competing financial institutions ("banks" for short). Banks can make standard loans on which plentiful historical data are available and unanimous agreement exists on default probabilities. Or banks can innovate and make new loans on which limited historical data are available, leading to possible disagreement over default probabilities. In equilibrium, banks make zero profits on standard loans and positive profits on innovative loans, which engenders innovation incentives for banks. But innovation brings with it the risk that investors could disagree with the bank that the loan is worthy of continued funding and hence could withdraw funding at an interim stage, precipitating a financial crisis. The degree of innovation in the financial system is determined by this trade-off. Welfare implications of financial innovation and mechanisms to reduce the probability of crises are discussed.

1. Introduction

Financial crises have long been a recurring phenomenon. The recent subprime lending crisis commenced with little warning and deepened quickly. The importance of this crisis was underscored by The Economist (2009) "Of all the economic bubbles that have been pricked, few have burst more spectacularly than the reputation of economics itself. For in the end, economists are social scientists, trying to understand the real world. And the financial crisis has changed that world."

Why do financial crises occur? While there are many theories, they can be broadly classified into three groups. One group is based on the notion that crises arise from panics that could be unrelated to the underlying fundamentals in the economy (e.g., Kindleberger, 1978). A second group of theories argues that crises arise from shocks to economic fundamentals and are therefore an intrinsic part of the business cycle (e.g., Mitchell, 1941). A more recent strand of the literature has focused on the role of the interconnectedness of banks and complexity (e.g., Caballero and Simsek, 2010). Allen and Gale (2007, 2008) provide an overview of this literature, and Rochet (2008) explores why banking crises occur with such alarming frequency.

In this paper, I adopt a different approach to explaining financial crises. I argue that, in a competitive financial system with no patent protection for innovations, profits of financial institutions ("banks" for short) get driven down to zero on any product that other banks also agree

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is worth offering.[1] Thus, if a bank offers a product whose risk is assessed in the same way by competitors as by the bank offering it, then competitive entry ensures that all banks earn zero profit; I call this a "standard loan." Incentives are thus created for banks to come up with innovative products that are less susceptible to poaching by competitors, when these products cannot be patent-protected. One way to achieve this is to create products on which historical default-risk data are either lacking or limited, so that scope for disagreement exists among banks about risk. In fact, the innovating bank can strategically innovate so as to choose the amount of potential disagreement that is likely to arise. This can be done by choosing the degree to which its competitors are likely to be familiar with the innovation. The closer the new product is to an existing product, the more familiar market players are with the default characteristics of the new product and the greater is the agreement over these characteristics. Introducing a product with lesser familiarity and higher potential disagreement induces less competition and thus generates higher profit potential for the innovating bank. But the dark side of innovation is that, subsequent to providing the initial funding, the bank's financiers could receive signals that induce them to disagree with the bank about the desirability of investing in the product. In this case, they could refuse to provide new funding to the bank to enable it to roll over short-term funding and keep the innovative loan on its balance sheet until maturity, causing premature liquidation of the loan. The more innovative the product, the greater this refinancing risk. If bank asset portfolios are partially opaque to investors, in the sense that there is noise in investors' assessment of which banks are making standard loans and which banks are making innovative loans, then investors could withdraw funding not just for those that made innovative loans, but also for some banks that made standard loans, when they come to believe the innovation is not worthwhile. Consequently, a financial crisis ensues.[2] The analysis is conducted in the absence of deposit insurance.

In addition to the main result about the link between innovation and financial crises, the analysis generates some testable predictions. First, financial innovation is greater in more competitive financial systems. Second, more innovative financial systems are more prone to financial crises. That is, periods during which complex new financial products are introduced are more likely to be followed by financial crises. Third, increasing the transparency of bank balance sheets for investors who fund banks can weaken banks' incentives to innovate.

The four key factors that interact in the analysis to engender a crisis are: (1) banking is competitive; (2) financial innovations cannot be patent-protected; (3) bank asset portfolios are opaque, but investors could observe a public signal that provides them with information about the quality of innovative loans as well as an indication of the bank's portfolio composition, and investors could disagree with banks about the profitability of the innovation; and (4) banks rely on short-term debt funding. Under these conditions, which are commonplace in modern banking, I show how a financial crisis can arise.

The butter and knife of innovation are one and the same thing—the lack of familiarity that others have with innovation. This lack of familiarity discourages competitors from rushing in and causing profit margins to be competed away, thereby protecting the innovator's profits. But the same lack of familiarity makes it more likely that short-term funding of the bank will not be rolled over, forcing it to abandon the innovation prematurely and shut down. Progress and crisis are intimately related: The elements that make innovation possible necessarily open the door to market instability. The core intuition of the paper thus captures both the lure of innovation and its danger via the essence of innovation, a newness that makes it possible for reasonable people to disagree on whether the innovation is a good or a bad idea.

This explanation, while it applies more broadly to financial crises, seems to be consistent with some striking circumstances surrounding the subprime crisis.[3] First, the crisis was preceded by major regulatory milestones (the 1994 removal of interstate branching restrictions and the November 1999 repeal of the Glass-Steagall Act in the U.S.) that significantly increased banking competition. Second, the crisis involved explosive growth in non-patent-protected new financial products that many market participants claim they did not understand. Third, the crisis was associated with increased complexity of bank balance sheets that made them more opaque to investors. And finally, the crisis involved institutions that were unable to roll over their short-term debt. These features correspond to the four factors discussed earlier that generate a crisis in the analysis here.

A few observations about the analysis in this paper are noteworthy. First, because the analysis focuses on non-patentable innovation, it deals primarily with financial innovation and financial crises. The absence of patent protection means imitation and correlated innovation

[1] Although I use the term "banks," the analysis is most appropriate for (de jure) uninsured financial intermediaries such as investment banks. It also applies to banks to the extent that they rely on uninsured funding sources.

[2] A key result that leads to a crisis is that the lead innovator chooses an *intermediate* degree of innovation in equilibrium. The intuition is that at one extreme there is no profit and at the other extreme there is too much risk. If the innovation is completely familiar, there is no disagreement over its value, and it invites so many competitors that only zero expected profits can be earned. If the innovation is sufficiently unfamiliar, then few competitors are likely to imitate, but the innovation distinguishes quite readily from the standard product in the eyes of the investors whose lack of familiarity with the innovation also generates a high probability that funding will not be renewed, causing the bank's liquidity to dry up. Thus, there is too much refinancing risk at this end of the innovation spectrum. By choosing an intermediate degree of innovation, the bank strikes the privately-optimal balance between opportunity and risk.

[3] While I believe that the innovation incentives generated by a competitive financial system represent an important causal factor in financial crises, there is no claim that this is the only factor. Many other factors, such as excessive short-term debt issued by intermediaries engaged in unregulated private-money creation (e.g., Stein, 2010), are deliberately excluded here in the interest of parsimony and focus. Caballero (2011) provides an interesting discussion of the various factors at work in generating crises. See also Allen and Gale (2007, 2008).

choices, which generate systemic risk. It also means that financial institutions seek non-patent-related forms of "protection" to preserve their innovation rents, and in the model developed here this is achieved by seeking relatively unfamiliar innovations that are less likely to be imitated.[4] And the less familiar is a new product that is adopted by a sufficient number of institutions, the more crisis-prone is the financial system. Moreover, the opaqueness of bank asset portfolios that plays a role in the analysis is a unique feature of financial institutions in that it is relatively easy for them to change the risk attributes of their asset portfolios without investors being able to noiselessly detect these changes, which, in turn, tends to make these portfolios less transparent to investors than is the case for non-financial firms (see, for example, Myers and Rajan, 1998).

Having said this, the analysis generalizes readily to nonfinancial innovations as a possible cause of crises. Even when technical innovations can be patent-protected, competitors can engage in limited forms of imitation and come up with products that do not cause patent infringement but are sufficiently close to the innovation to create competitive dynamics similar to those analyzed in the model. Therefore, firms that invest in technical innovations could also seek relatively unfamiliar innovations to make imitation less likely.[5] For technical innovations, the risk of unfamiliar innovations could come from a variety of sources. For example, the innovation could simply fail, bringing down the lead innovator as well as those who imitated with similar innovations. That is, with more unfamiliar innovations, the technological risk of failure could be high and this risk could become systemic if there are sufficiently many close imitators. Another reason could be that even a good innovation could suffer from lack of demand because customers are unfamiliar with it. This has some similarity to the drying up of short-term funding from banks due to lack of familiarity with a financial innovation.

Second, because this is an analysis in which different agents disagree, it is not possible to identify an unambiguous social optimum. Nonetheless, with some additional structure, one can conduct a welfare analysis before beliefs are drawn. This analysis establishes conditions under which the privately optimal degree of innovation exceeds the social optimum. Capital requirements can be used to move the private optimum toward the social optimum. I also examine what happens if the government steps in and tries to prevent the crisis when it first surfaces. I argue that this induces banks to be more innovative, but bad innovations have a higher probability of being launched and subsequently sustained. This, in turn, increases the likelihood of future crises.

Third, moral hazard and hubris have been discussed extensively as contributors to financial crises, most notably the recent subprime crisis (e.g., Litan and Bailey, 2009). While the impact of these factors cannot be denied, what this paper shows is that a financial crisis could occur even if moral hazard and hubris are expunged. The likelihood of a financial crisis is rooted in the fundamental economics of a competitive financial services industry and the nature of innovation.

Finally, discussion is ongoing about how financial crises can dampen innovation incentives (e.g., Litan and Bailey, 2009). A contribution of this paper is that the causality is reversed. It is, in fact, financial innovation that causes crises.

This paper is related to the vast literature on financial crises (e.g., Allen and Carletti, 2006, 2008; Allen and Gale, 2000a, 2000b; Boyd, Kwak, and Smith, 2005), including papers that have shown theoretically that financial crises can be optimal. For example, Allen and Gale (1998) show that bank runs can facilitate the attainment of a first-best equilibrium with efficient risk sharing between early and late withdrawing depositors. Brunnermeier and Sannikov (2010) develop a macroeconomic model in which volatility spikes could cause long-term price depressions and elevated price correlations, and risk sharing within the financial sector can amplify systemic risks. Unlike these papers, the focus here is on the role of competition-induced, endogenously arising incentives for financial innovation in causing crises.

Recent papers have analyzed the role of network complexity. Allen, Babus, and Carletti (in press) develop a model in which institutions become connected and form networks through swaps of projects to diversify their individual risks. They show that when institutions use short-term finance, the network structure generates systemic risk and welfare differs across different network structures. Thus, one similarity between that paper and this paper is that short-term funding of banks plays a role in generating systemic risk.[6] Caballero and Simsek (2010) show that when conditions deteriorate, endogenous uncertainty increases as banks face a more complex environment, which could cause liquidity to vanish and a crisis to ensue. The key difference is that the network effects analyzed in these papers are absent in this paper and the focus here is on the complexity or innovativeness of financial products themselves.

This paper is also related to the literature on financial innovation. Gale (1992) introduced the concept of "unfamiliar securities" and suggested that the cost of gathering information about such securities could lead to gains from standardization. He derives conditions under which standardization emerges as an equilibrium phenomenon. In this paper, too, there are unfamiliar and standard securities, but the focus is the opposite to the one in Gale (1992), in that conditions are derived here under which unfamiliar securities emerge in equilibrium. Tufano (1989) empirically studies various financial innovations to understand the gains to innovators. Consistent with the

[4] As an alternative to the approach here, Boot and Thakor (2000) propose that banks could seek to protect their rents against competitive forces by engaging in lending that focuses on building deeper relations with borrowers.

[5] With technical innovations, the reason that unfamiliar innovations might not be mimicked is more likely to be because competitors find it more difficult or costly to acquire the same innovation through their own research and development, rather than because of higher refinancing risk.

[6] Huang and Ratnovski (2011) have also theoretically examined the risks associated with wholesale bank funding of this sort.

assumptions in this paper, he shows that investment banks that create new products enjoy only a brief period of monopoly before imitative products appear. He finds that innovations help banks to become inframarginal competitors and capture a larger share of underwriting than captured by other banks. Frame and White (2004) point out that the welfare effects of financial innovation appear to be positive.

A small but emerging literature has begun to explore potential linkages between innovation and crises. Biais, Rochet, and Woolley (2009) develop a model in which they assume that when managers choose innovative projects, it is inherently more difficult for investors to monitor them, leading to higher managerial rent-seeking. That is, whereas I distinguish an innovative project from a standard project on the basis of disagreement, their distinction is that innovative projects are prone to moral hazard and standard projects are not. They go on to show that when managerial rent-seeking becomes excessive, investors give up on trying to control managerial incentives, and a crisis arises if the innovation is fragile. Other papers have emphasized the interaction between innovation and high bank leverage in generating crises. Shleifer and Vishny (2010) propose a theory of financial intermediaries operating in markets influenced by investor sentiment and show that an innovation such as securitization implies a trade-off for banks between short-term profits and instability that induces excessive lending and leverage. Rajan (2006) stresses how financial innovation has led to the emergence of intermediaries who can by themselves induce crises due to their leverage and risk appetite. In contrast to this literature, the analysis here focuses on why innovations arise in markets and generate crises even without investor sentiment or excessive leverage. Gennaioli, Shleifer, and Vishny (in press) argue that "neglected risk" in innovative financial products, combined with limited supply of standard or traditional safe products, results in excess demand for innovative products.[7] When the neglected risks are realized, investors dump these innovative products, causing banks to be stuck with them. By contrast, standard products are available in elastic supply in this paper, and there are no neglected risks in financial products.

The rest of the paper is organized as follows. Section 2 develops the model. Section 3 contains the analysis of the innovative and standard loan markets. Section 4 combines the analyses of innovative and standard loans in Section 3 to show how innovation can generate a crisis, and it contains the overall analysis of the equilibrium in the financial system, including an endogenization of the number of banks. Section 5 discusses the welfare implications of the analysis. Section 6 concludes. Appendix A contains the extension of the model that endogenizes short-term bank debt and the bank's capital structure. Proofs of most results are in Appendix B.

[7] Such excess demand can lead to price bubbles, an issue examined in Pastor and Veronesi (2009). They develop a general equilibrium model in which the stock prices of innovative firms exhibit bubbles during technological revolutions. These bubbles eventually burst.

2. The model

In this section, I describe the model. I begin with a description of the key agents in the model, their preferences, and the information structure. This is followed by a description of how financial intermediation works in the model. I close with a summary of the sequence of events and the time line.

2.1. Agents, preferences and information

There are three dates ($t=0,1,2$), two time periods, and three types of agents in the model: financial intermediaries, those seeking financing by selling debt securities to financial intermediaries, and investors providing financing to the intermediaries by purchasing their debt contracts. It is convenient to call the financial intermediaries "banks" and refer to those seeking financing from financial intermediaries as "borrowers," although it should be understood that a broader class of intermediaries than just banks is being modeled. For example, one could just as easily think of the intermediaries here as investment banks because they are funding with short-term, uninsured liabilities. Similarly, investors who provide financing to intermediaries could be thought of as depositors in the case of banks, but they might simply be institutional providers of short-term debt who specialize in financing intermediaries such as investment banks. The claims of investors are uninsured, consistent with the notion that I am talking about a broader class of intermediaries than insured depository institutions. The analysis is applicable to insured depositories as long as deposit insurance pricing is risk-sensitive or these intermediaries fund at least partly with uninsured liabilities or both.[8] There is universal risk neutrality and the single-period riskless rate is $r>0$.

At $t=0$, each borrower takes a \$1 loan from a bank that matures at $t=2$. Banks, in turn, fund themselves with two types of claims: equity (E) and debt (D). The debt is short term, so that the debt raised at $t=0$ matures at $t=1$ and must be replaced with new one-period debt for the bank to continue funding the loan. While I take this maturity mismatch between loans and debt as well as the bank's capital structure as given for now, these are endogenized in Appendix A. To preview that analysis, the bank's debt is short term because it provides the usual market discipline on the bank.

At $t=0$, the bank can either invest in a standard loan or find an innovative loan to invest in. I use the term "loan" as an allegory for any financial product the intermediary could invest in, so it need not be a bank loan. The distinction between standard and innovative loans is made clearer later in this section. For now, think of a standard loan as one on which a long time series of historical default-risk data are available because it is a product that has been in existence for a long time, and an innovative loan as a product that has never been offered

[8] I sidestep here the issue of the feasibility of implementing a risk-sensitive deposit insurance scheme in a competitive credit market. See Chan, Greenbaum, and Thakor (1992).

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before and hence is lacking in historical default-risk data. At $t=0$, there are N banks and M borrowers who need standard loans.

At $t=1$, additional information about the loans of each bank could be revealed to the market via a noisy signal. Conditional on this information, investors decide whether or not to provide the bank with new one-period financing for another period.

At $t=2$, the economy comes to an end. Borrowers repay banks if they can, and banks repay their shareholders as well as investors who provided debt financing from the funds available.

2.2. The nature of financial intermediation

Entry into banking is unrestricted at some point before $t=0$, say $t=-1$, but each bank bears a small cost $C>0$ of entering the industry at $t=-1$. There is no entry after $t=-1$.

2.2.1. Bank's role

A bank has the capacity to make one loan. It must decide between a \$1 standard loan (s) and a \$1 innovative loan (n). Both loans have a two-state payoff distribution, with a positive payoff with some probability and a zero payoff with the complement of that probability. In Appendix A, I allow the payoff distribution of the loan to be dependent on the bank's (privately costly) effort choice. For now the payoff distributions are taken as given, as described below.

2.2.2. Standard loans

A borrower that takes a \$1 standard loan uses it to finance a two-period project that pays off R at $t=2$ if it succeeds and zero at $t=2$ if it fails. The probability of success is $p_s \in (0,1)$. If the loan is prematurely liquidated at $t=1$, it pays off 0. The portion of the project payoff that can be pledged is $X \in (0,R)$, so the repayment promised by the borrower to the bank cannot exceed X.[9] Moreover, $p_s X > [1+r]^2$. The standard loan is one that banks have made repeatedly in the past. Consequently, a long time series of historical default-risk data is available, and all agents agree on all attributes of the loan, i.e., on p_s, R, and X.

2.2.3. Innovative loans

The bank can also choose to invest in an innovative loan instead of a standard loan. This loan is to a borrower with an unprecedented project on which there is no time series of historical default-risk data. Thus, different agents can have different prior beliefs about the probability of success of the new project, p_n. Let $p_n \in \{p_\ell, p_h\}$, with $p_\ell \in [0,1)$, $p_h \in (0,1)$, and $p_\ell < p_h$, so the new project pays off $R_n > R$ at $t=2$ with probability p_n and zero with probability $1-p_n$. For simplicity, set $p_\ell \equiv 0$, so the subscript on p_h can be dropped and set $p_h \equiv p \in (0,1)$, with $p > p_s$. The portion of the project payoff that can be pledged is $X < R_n$, and because $p > p_s$, it follows that $pX > p_s X > [1+r]^2$. It is socially efficient to invest in the innovative project only if the bank believes that $p_n = p$. Moreover, when $p_n = p$, the innovative project has higher expected value than the standard project, i.e., it adds more value to the economy. Premature liquidation of the innovative loan at $t=1$ also yields a payoff of zero.

2.2.4. The lead innovator and the possibility of disagreement

Let $\theta \in (0,1)$ be the probability that the bank that comes up with the idea of investing in the innovative loan draws a prior belief at $t=0$ that $p_n = p$. The bank clearly pursues the innovation only in this case and eschews it if it draws a belief $p_n = 0$. For simplicity, I focus on the case in which only one bank discovers an innovative project to fund and other banks decide to either participate in that market or simply stick to making standard loans. Therefore, I avoid examining the more complicated situation in which multiple banks are simultaneously pursuing different innovations. It is assumed that after the innovating bank has drawn a prior belief about the success probability of the new project, the remaining $N-1$ banks get to learn about the existence of this innovative project at $t=0$, but this happens if, and only if, the innovating bank decides to make a loan to the borrower with the innovative project.

This specification is meant to capture two ideas: (1) competing banks cannot learn about the innovative loan if it is never made in the first place by the innovating bank; and (2) financial innovations, unlike patentable innovations, have no protection per se against imitation, so if competing banks like the innovative loan, they can make it, too. However, given the lack of historical data, other banks could draw different beliefs about the success probability of the new project and hence the default risk of the innovative loan. Following Kurz (1994) these heterogeneous prior beliefs are all rational beliefs. The Kurz notion of rational heterogeneous priors is a more reasonable and general specification than the standard common-priors specification when one is dealing with a new event for which no historical data are available (see Kreps, 1990; Morris, 1995).[10]

So, even though the innovating bank draws a belief that $p_n = p$ and pursues the innovative loan, some other bank could draw $p_n = 0$ and shy away from innovative loans. Let the maximum demand for innovative loans be J. That is, there are J borrowers with new projects who

[9] The main role of the assumption that not all of the project payoff can be pledged to repay the bank is to ensure that in the state in which an innovating bank is a monopolist, not all project surplus is extracted by the bank, and the borrower is strictly better off participating than not participating in the credit market. An additional implication is that in the social welfare analysis, it represents another wedge between the social and private optima, as the social planner cares about the total project payoff R and the bank cares only about the portion it can extract, which has an upper bound of X. In Lemma 2 the assumption about how much of the project payoff can be pledged also plays a role in the uniqueness of the Nash equilibrium.

[10] Heterogeneous priors have been used in numerous recent papers to explain a variety of phenomena including the interaction of banks and markets (Allen and Gale, 1999), security issuance and capital structure (Boot and Thakor, forthcoming; Dittmar and Thakor, 2007), the choice between private and public ownership (e.g., Boot, Gopalan, and Thakor, 2006, 2008), the matching of assets and liabilities on bank balance sheets based on value added (e.g., Song and Thakor, 2007), "endogenous" optimism (e.g., Van den Steen, 2004), and the theory of the firm (e.g., Van den Steen, 2010).

become visible to banks only if the innovative bank decides to extend one of these borrowers a loan. The innovative bank also could draw a belief $p_n=0$ (with probability $1-\theta$), and if it goes ahead nonetheless with a loan to this borrower, other banks might draw $p_n=p$ and find this a value-enhancing loan. However, the lead innovator never makes the innovative loan in this case, so no other banks have an opportunity to observe the innovations and follow suit.

2.2.5. "Familiarity" of innovation

How likely is it that another bank will view an innovative loan as creditworthy when the innovative bank invests in it? In general, this likely depends on how similar the innovative loan is to loans these banks made in the past. The more familiar the innovative loan is to banks, the more likely it is that they view it as a loan worth investing in. The innovativeness of the innovative loan is related to its degree of familiarity, with lower familiarity representing greater innovativeness. Let the degree of familiarity be $\rho \in [0,1]$. The probability, $q(\rho)$, that a competing bank draws the same prior belief about the success probability of the innovative loan as the innovating bank, conditional on the innovating bank making the innovative loan, is monotonically increasing in ρ and could also depend on other parameters, such as how many other banks are innovating. I assume that the innovating bank can choose how innovative to make the new loan, and thereby how likely it is that the assessments of competing banks are the same as its own assessments. That is, the innovating bank can choose the familiarity variable ρ. The idea is that there are many sets of borrowers, with each set possessing a new project of some sort. All sets of borrowers possess projects that are unprecedented, but some sets are less familiar than others. The newer the projects, the more likely banks are to diverge in their assessments of project risks.[11] By its choice of how familiar the new project is that it invests in, the bank can influence the likelihood that other banks agree with its assessment of the credit risk of the innovative loan. The number of banks willing to make innovative loans is N_n, which will be endogenized later. The bank's choice of ρ cannot be observed by anyone but the bank itself.

2.2.6. Bank portfolio opaqueness

Bank portfolios are opaque to investors at $t=0$ in the sense that investors cannot determine at $t=0$ whether a particular bank has invested in an innovative loan or a standard loan. There is partial opacity at $t=1$ because investors receive a noisy signal about each bank's portfolio composition at $t=1$. Investors can then use this signal to calculate the probability that a given bank has invested in a particular kind of loan, but they cannot have a deterministic assessment of any bank's portfolio composition at any time.

2.2.7. Investors

I assume that even though other banks have the opportunity to learn about the innovative loan default probability at $t=0$, investors and bank shareholders have this opportunity only at $t=1$. At this time, investors draw a prior belief $p_n \in \{0,p\}$, and the probability that their prior belief coincides with that of the innovating bank is ρ. This signal pertains to the innovation itself and hence affects all banks that adopt the innovation, i.e., it is a signal that is a source of systematic risk for innovation adopters.

At $t=1$, investors also receive a signal, ϕ, about the bank's portfolio composition, where $\Pr(\phi=n|n,\rho) \equiv \gamma(\rho) \in (0.5,1) \forall \rho$, with $\gamma'(\rho)<0$, and $\lim_{\rho \to 0} \gamma(\rho)=1$, so that the greater the innovativeness of the loan (the smaller the ρ), the higher is the probability that a bank that has chosen an innovative loan is revealed as such through the investors' signal. Moreover, $\gamma''(\rho)>0$ and $\Pr(\phi=s|s) \equiv \overline{\gamma} \in (0.5,1)$ with $\lim_{\rho \to 1} \gamma(\rho)=\overline{\gamma}$. That is, as an innovative loan becomes less innovative (as ρ increases), the signal distribution converges to that of the standard loan. Moreover, with this signal, $\Pr(\phi=n|n,\rho) > \Pr(\phi=n|s) \forall \rho<1$, i.e., $\gamma(\rho) > 1-\overline{\gamma} \forall \rho<1$. This is obviously true because $\overline{\gamma}>0.5$ and $\gamma(\rho)>\overline{\gamma} \forall \rho<1$. Similarly, $\Pr(\phi=s|s) > \Pr(\phi=s|n,\ \rho) \forall \rho<1$, $\overline{\gamma}>1-\gamma(\rho) \forall \rho$, which is obviously true because $\overline{\gamma}>0.5$ and $1-\gamma(\rho)<0.5 \forall \rho$. This is a bank-specific signal, i.e., it is a source of idiosyncratic risk for each bank.

The γ function is shown in Fig. 1. The motivation for this function is that the more different an innovative product is from the standard loan (the lower is ρ), the easier it becomes for investors to distinguish it from the standard loan. In the limit, as $\rho \to 1$, the difference

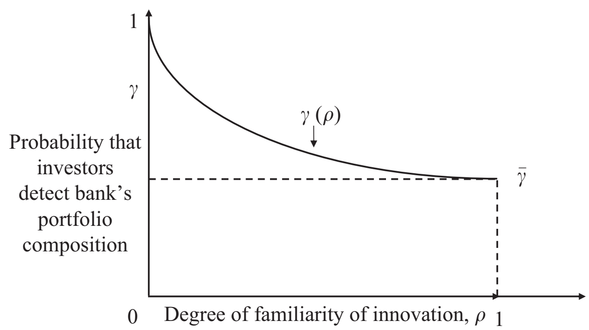

Fig. 1. The γ function.

[11] This divergence is symmetric in that $1-q(\rho)$ is the probability that other banks believe $p_n=0$ when the lead innovator believes $p_n=p$ and it is also the probability that other banks will believe $p_n=p$ when the lead innovator believes $p_n=0$. However, when the lead innovator believes $p_n=0$, the other banks have no opportunity to observe the innovative loan, so no bank makes such a loan. Assuming belief heterogeneity is a convenient way to capture the idea that making a loan less familiar reduces competition, and it can subsume alternative specifications. For example, the less familiar a new financial product, the greater could be the expertise needed to determine if it is good for a particular bank. The a priori profitability of the innovation, in the absence of such expert determination, is negative for any bank. While the lead innovator has the expertise, the measure of other banks that have it declines as the innovation becomes less familiar. This is consistent with the notion of cross-sectional heterogeneity in human capital investments leading to differing degrees of innovation in firms (e.g., Sevilir, 2010). Such a specification yields an effect of innovation familiarity on competition that is qualitatively similar to that of belief heterogeneity.

between the innovative and standard loans vanishes and it is impossible for investors to tell them apart.

The assumptions that investors do not observe the composition of the bank's loan portfolio at $t=0$, get only a noisy signal about it at $t=1$, and receive information about the default probability of the innovative loan only stochastically and with a lag capture the idea that bank loan portfolios are at least partially opaque to investors. They often receive only limited information and that, too, with a lag. In fact, the investors' signal at $t=1$ could be viewed as a signal that is derived from noisy initial observations about the performance of the innovative asset prior to payoff realization at $t=2$. It is assumed that the single-period (reservation) expected rate of return for investors is r.

2.2.8. The loan market

The operation of the loan market can be summarized as follows. First, the number of banks that participate in the innovative loan market is endogenously determined, based on the beliefs banks draw about N_n. Banks that choose not to make innovative loans participate in the standard loan market. Then borrowers seeking innovative loans indicate the price they are willing to pay and banks indicate which of these borrowers they are willing to lend to. From the acceptable set of borrowers, each borrower is randomly assigned to a bank to ensure that loan demand equals loan supply. If loan supply exceeds loan demand, banks that are not involved in the innovative loan market participate in competing in the standard loan market. What kind of loan the bank ends up making (innovative or standard) is privately observable only to the bank manager at $t=0$.

It is assumed that the one-period cost of equity capital to the bank is $k_e > r$. Because investors are risk neutral, this assumption requires some justification. One possible justification is that the transactions costs of issuing equity are higher, ceteris paribus, than the costs of issuing debt.[12] Another justification is that adverse-selection costs associated with equity are likely to be higher than those associated with debt (e.g., Myers and Majluf, 1984). For other papers that use the assumption that bank equity is costly, relative to debt financing, see, for example, Allen, Carletti, and Marquez (2011) and Mehran and Thakor (2011). This assumption is not crucial to the analysis, however, and the bank finances with a mix of debt and equity even if $k_e=r$. See the discussion in Appendix A.

2.2.9. Definition of financial crisis

A financial crisis occurs when investors are not willing to provide funding to the majority of banks in the financial system.

2.3. Summary of sequence of events and time line

At $t=-1$, the number of banks in the industry is endogenously determined so that each bank earns zero expected profit, taking into account its entry cost, C.

At $t=0$, one (randomly chosen) bank decides whether it will be the one that discovers an innovative loan. Every bank decides whether to invest in a standard loan or an innovative loan at $t=0$. Financing for the loan comes from equity capital, E, and one-period debt, D, with $D+E=1$. Which loan is chosen by the bank is privately observed only by the bank. The loan market operates as described in Section 2.2.8.

At $t=1$, investors receive a public signal about the credit quality of the innovative loan and use it to form their beliefs about p_n. The probability that they will draw a belief $p_n=p$ that coincides with the belief of the innovating bank is ρ. In this case, new one-period debt is available to the bank at $t=1$. Investors also receive a bank-specific signal ϕ about each bank's loan portfolio. It is shown later that if the signal reveals $\phi=n$ and if investors draw a belief $p_n=0$, they do not provide new debt at $t=1$ and the bank is forced to liquidate; first-period investors receive zero. There could be parameter values for which investors could refuse to provide funding even if $\phi=S$; this is examined later. If the loan is not liquidated, the bank continues for the second period.[13]

At $t=2$, a bank that was not liquidated at $t=1$ collects on its repayment from the borrower if the borrower's project succeeds. Investors are paid off first, and the bank's shareholders are paid the rest. Fig. 2 summarizes the sequence of events described thus far. It corresponds to the version of the model in which debt maturity and the bank's capital structure are not endogenized, and, thus, does not include the additional features included in Appendix A.

3. The analysis of the markets for innovative and standard loans

This section presents an analysis of the model. It begins by examining equilibrium in the market for innovative loans, followed by an analysis of equilibrium in the market for standard loans. The section ends by collecting the assumed parametric restrictions. In this analysis, take as given that the bank is financed with a mix of debt (D) and equity (E). The bank's capital structure is endogenized in Appendix A.

3.1. Analysis of the innovative loan market: events at $t=1$

I proceed in the usual backward induction manner by first examining what happens at $t=1$. Focus on a bank that drew a belief $p_n=p$ and extended the innovative loan at $t=0$. Now, if investors draw $p_n=p$ after observing the

[12] Lee, Lochhead, Ritter, and Zhao (1996) show that the average transaction cost of a seasoned equity offering in the U.S. during 1990–1994 was 7.11% versus an average transaction cost of debt 2.24% for a straight debt issue. However, even though equity could be more costly than debt, Mehran and Thakor (2011) show that the value of the bank and the amount of equity in its capital structure are positively related in the cross-section.

[13] A slightly different specification of the loan market would be one in which the innovativeness of the loan is fixed and ρ represents the fraction of the lead innovator's portfolio that is composed of the innovative loan. A competitor is more likely to detect the innovation and imitate it the higher is ρ. This specification also yields results similar to my set-up.

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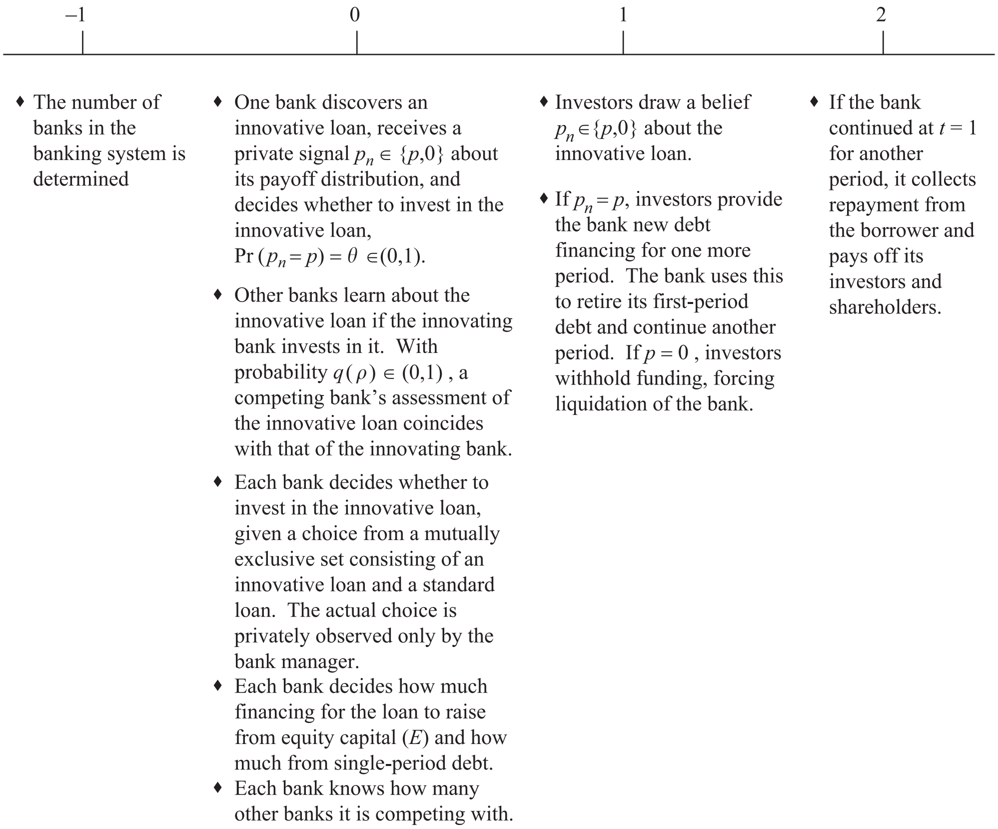

Fig. 2. Time-line for sequence of events.

public signal about the innovative loan at $t=1$, then it is clear that investors will agree to provide new one-period funding to the bank for another period, given that first-period investors initially provided the funding at $t=0$ before observing the public signal. What if investors believe $p_n=0$? This assumes that a bank will have extended the innovative loan at $t=0$ only if the bank itself drew $p_n=p$. It is trivial to verify that the bank will never make an innovative loan if it draws $p_n=0$.

The goal is to first find a sufficiency condition for investors at $t=1$ to refuse to provide new financing to the bank if these investors draw $p_n=0$ and get a signal $\phi=n$. For this, some preliminaries are needed. Let $1+r_0$ be the repayment to first-period investors per dollar borrowed at $t=0$. That is, the bank's total repayment obligation is $[1+r_0]D$. If the bank is to continue for another period at $t=1$, it needs to borrow $[1+r_0]D$ to pay off first-period investors. Whether this second-period debt financing is available at $t=1$ depends on the ϕ signal investors observe at $t=1$, in addition to drawing $p_n=0$.

The maximum amount of innovative loan financing that could have occurred at $t=0$ is J. Suppose the number of banks that drew $p_n=p$ about the innovative loan is $N_n \leq N$. Then, the probability that the supply of innovative loans from banks exceeds the demand is given by

$$\Pr(N_n > J) \equiv \beta_J. \tag{1}$$

When supply exceeds demand, not every bank is able to participate in the market for innovative loans. The probability that a bank that is willing to participate will be able to do so is J/N_n, and the probability that a bank that is willing to participate will be unable to do so is $[1-(J/N_n)]$. Clearly, β_J is the probability that the number of banks that adopt the innovation introduced by the lead innovator is at least J.[14] Since the probability, q, that a bank will draw a signal that agrees with the signal of the lead bank is increasing in ρ, it follows that $\partial\beta_J/\partial\rho > 0$. It is further assumed that $\partial^2\beta_J/\partial\rho^2 \geq 0$ and that $\lim_{\rho\to 0}\beta_J = 0$, $\lim_{\rho\to 1}\ \beta_J = 1$.

3.1.1. Investors' beliefs

Investors cannot directly observe at the outset (at $t=0$) whether a bank has made an innovative or a standard loan. They also cannot observe the ρ associated with an innovative loan. Thus, they have to make a probabilistic assessment about whether a given bank made a standard or innovative loan based on their expectation about the lead innovator's choice of ρ in equilibrium and the associated β_J. Based on the above, one can write down the prior probability (as assessed by investors) that the bank made a standard loan. Let λ_s be the investors' prior probability that the bank made a standard loan, and $\lambda_n \equiv 1-\lambda_s$, the investors' prior probability that the bank

[14] If $q(\rho) \equiv \rho$, then $\beta_J = \sum_{i=J}^{N} \rho^i [1-\rho]^{N-i}$. Moreover, when the number of banks that adopt the innovation pioneered by the lead bank is added to the lead bank, $J+1$ or more banks are competing in the innovative loan market.

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made an innovative loan. The exact expressions for λ_s and λ_n are in Appendix B. Subsequent to forming these priors, investors observe the signal ϕ about each bank's portfolio and arrive at their posterior beliefs. Now, let λ_s^i be the posterior belief of investors that the bank made a standard loan, after investors observe a signal $\phi=i$, $i\in\{s,n\}$, about the bank's portfolio. Similarly, let λ_n^i be the posterior belief of investors that the bank made an innovative loan, after investors observe a signal $\phi=i$, $i\in\{s,n\}$. Thus, the posterior beliefs are

$$\Pr(\text{standard loan}\,|\,\phi=S)\equiv\lambda_s^s=\frac{\overline{\gamma}\lambda_s}{\overline{\gamma}\lambda_s+[1-\gamma(\rho)][1-\lambda_s]},\tag{2}$$

$$\Pr(\text{innovative loan}\,|\,\phi=S)\equiv\lambda_n^s=1-\lambda_s^s=\frac{[1-\gamma(\rho)][1-\lambda_s]}{\overline{\gamma}\lambda_s+[1-\gamma(\rho)][1-\lambda_s]},\tag{3}$$

$$\Pr(\text{innovative loan}\,|\,\phi=n)\equiv\lambda_n^n=\frac{\gamma(\rho)[1-\lambda_s]}{\gamma(\rho)[1-\lambda_s]+[1-\overline{\gamma}]\lambda_s},\tag{4}$$

and

$$\Pr(\text{standard loan}\,|\,\phi=n)\equiv\lambda_s^n=1-\lambda_n^n=\frac{[1-\overline{\gamma}]\lambda_s}{\gamma(\rho)[1-\lambda_s]+[1-\overline{\gamma}]\lambda_s},\tag{5}$$

for the two possible values of the signal ϕ.[15]

3.1.2. Interest rates

Having computed these posterior (post-signal ϕ) beliefs of investors at $t=1$, it is now possible to compute the state-contingent interest rates that investors charge on this debt at $t=1$. There are four interest rates to consider, one corresponding to each of four cases: (1) investors draw $p_n=0$ and $\phi=n$, (2) investors draw $p_n=0$ and $\phi=S$, (3) investors draw $p_n=p$ and $\phi=n$, and (4), investors draw $p_n=p$ and $\phi=S$.

Case 1. Suppose the interest rate that investors charge the bank on the new one-period debt at $t=1$, conditional on $p_n=0$ and $\phi=n$, is $r_1^n(0)$, if credit is extended. Then, $r_1^n(0)$ is set to satisfy the second-period investors' participation constraint. The detailed expression for this participation constraint is provided in Appendix B. It can be written as

$$\lambda_s^n p_s[1+r_1^n(0)]+\lambda_n^n[0][1+r_1^n(0)]=1+r.\tag{6}$$

Note that λ_S^n, the posterior probability that a bank on which an innovative loan signal was received made a standard loan, is multiplied by $p_s[1+r_1^n(0)]$, the expected value at $t=1$ of the investors' payoff at $t=2$ with a standard loan. Similarly, the posterior probability that a bank on which $\phi=n$ was observed made an innovative loan, λ_n^n, is multiplied by $[0][1+r_1^n(0)]$, the present value at $t=1$ of the investors' expected payoff at $t=2$ with an innovative loan to which investors attach a success probability of $p_n=0$.

Solving for $r_1^n(0)$ from Eq. (6) gives

$$1+r_1^n(0)=\frac{1+r}{\lambda_s^n p_s}.\tag{7}$$

Thus, the bank's repayment obligation at $t=2$ becomes $[1+r_0][1+r_1^n(0)][1-E]$. The sufficiency condition for investors to refuse to extend funding at $t=1$ conditional on $p_n=0$ is

$$\frac{[1+r_0][1-E][1+r]}{\lambda_s^n p_s}\equiv\overline{X}>X,\tag{8}$$

where X is the maximum pledgeable payoff from the borrower's project. If Eq. (8) holds, then the expected repayment on the bank's debt that investors need to break even exceeds the maximum amount investors can collect from the bank (which itself constrainted by the borrower's maximum pledgeable income), so investors refuse funding. Later, r_0, ρ, and E are endogenously solved for, so that Eq. (8) can be stated purely as a restriction on exogenous parameters. Essentially, Eq. (8) will hold for λ_s^n sufficiently small, which means it holds for $\overline{\gamma}$ sufficiently large because λ_s^n is decreasing in $\overline{\gamma}$ (see Eq. (5)), i.e., if the investors' signal about the portfolio composition of a bank that made a standard loan is sufficiently precise.

Case 2. Now consider the case in which investors draw $p_n=0$ and observe $\phi=s$. Let $r_1^s(0)$ be the interest rate that investors charge on the new on-period debt at $t=1$. Following steps similar to those above, I can derive

$$1+r_1^s(0)=\frac{1+r}{\lambda_s^s p_s}.\tag{9}$$

The sufficiency condition for investors to be willing to extend funding is

$$[\lambda_s p_s]^{-1}[1+r_0][1-E][1+r]\equiv\underline{X}<X.\tag{10}$$

If Eq. (10) holds, then a bank that has made a loan on which the borrower's promised repayment is sufficiently high but still feasible (i.e., below the borrower's maximum pledgeable income) would be able to obtain one-period debt financing. This is because such a bank can promise investors enough to enable them to break even. Note that $\lambda_s^s>\lambda_s^n$, so Eqs. (8) and (10) can be satisfied together.

Case 3. Next is the case in which investors draw $p_n=p$ and observe $\phi=n$. Let $r_1^n(p)$ be the interest rate that investors charge on the new one-period debt at $t=1$. The investors' participation constraint can now be written as

$$\lambda_s^n p_s[1+r_1^n(p)]+\lambda_n^n p[1+r_1^n(p)]=1+r.\tag{11}$$

Solving for $r_1^n(p)$ yields

$$1+r_1^n(p)=\frac{1+r}{\lambda_s^n p_s+[1-\lambda_s^n]p}.\tag{12}$$

Because $p>p_s$ and $\lambda_s^s>\lambda_s^n$, if Eq. (10) holds, then $1+r_1^n(p)<X$. This means investors are willing to refinance the bank at $t=1$ for a promised repayment that is feasible for the bank, given the borrower's maximum pledgeable income.

[15] To see the economics underlying these posterior beliefs, consider Eq. (2), for example. In the numerator, $\overline{\gamma}$, the probability that investors observe a signal $\phi=S$ when the bank has chosen a standard loan, is multiplied by λ_S, the prior probability that the bank chose a standard loan. The denominator is the unconditional probability of observing $\phi=S$ (which includes the probability that $\phi=S$ is generated on a bank that chose an innovative loan). The other expressions (Eqs. (3) and (5)) have similar interpretations.

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Case 4. Now consider the case in which investors draw $p_n=p$ and observe $\phi=s$. Let $r_1^s(p)$ be the interest rate that investors charge on the now one-period debt at $t=1$. Then,

$$1+r_1^s(p)=\frac{1+r}{\lambda_s^s p_s+[1-\lambda_s^s]p}. \tag{13}$$

Further, because Eq. (10) holds, it also follows that $1+r_1^s(p)<X$, so the bank can refinance at $t=1$.

Lemma 1. Assume that Eq. (8) and (10) *hold in equilibrium. Then, if investors draw $p_n=p$, they provide second-period funding to any bank regardless of the signal ϕ observed about that bank's portfolio. If investors draw $p_n=0$, they provide second-period funding only if they observe $\phi=s$.*

Lemma 1 implies that a financial crisis occurs if investors draw $p_n=0$ and then $\phi=n$ for sufficiently many banks. This by itself is not enough, however, because it has not been established that any bank will choose to make an innovative loan at $t=0$ and also choose $\rho<1$, given that doing so creates the likelihood of a financial crisis at $t=1$. This analysis is provided later in this section.

Table 1 describes the four states at $t=1$, the probabilities of these states, and the outcomes.

Because second-period funding is denied in state 4, I need only the second-period interest rates for the first three states: $r_1^s(p)$, $r_1^n(p)$ and $r_1^s(0)$, which were computed earlier.

3.2. Analysis of the innovative loan market: events at $t=0$

The main goals here are to solve for the relevant interest rates the bank has to pay on its borrowing and the rates it will charge borrowers, and to examine the bank's decision to participate in the innovative loan market.

3.2.1. Interest rates

Because first-period investors are repaid in full when the bank is able to raise second-period financing and not at all when it cannot, the probabilities of repayment for the investors are obtained by adding the probabilities of states 1, 2 and 3. These are also the probabilities the bank will be able to continue for a second period.

For a bank that invested in a standard loan at $t=0$, the probability of repayment for investors is

$$\delta_S=[\rho\overline{\gamma}+\rho[1-\overline{\gamma}]+[1-\rho]\overline{\gamma}]=\rho+\overline{\gamma}[1-\rho]. \tag{14}$$

For a bank that invested in an innovative loan at $t=0$, the probability of repayment for investors is

$$\begin{aligned}\delta_n&=\{\rho[1-\gamma(\rho)]+\rho\gamma(\rho)+[1-\rho][1-\gamma(\rho)]\}\\&=\rho+[1-\rho][1-\gamma(\rho)].\end{aligned} \tag{15}$$

I can now determine how first-period investors set r_0, the interest rate they charge on the first-period debt. Recalling that λ_s is the prior probability assigned by investors that the bank made a standard loan and λ_n is the prior probability that the bank made an innovative loan, I can write:

$$\{\lambda_s\delta_s+\lambda_n\delta_n\}\{1+r_0\}=1+r. \tag{16}$$

To interpret this break-even condition, note that the promised repayment on the first-period debt, $[1+r_0]$, is multiplied by the probability that the bank will be able to repay, which is the probability that the bank will be able to refinance its debt at $t=1$. This probability is λ_s (the probability the bank has made a standard loan) times δ_s (the probability that a bank that has made a standard loan will be able to refinance at $t=1$) plus λ_n (the probability the bank made an innovative loan) times δ_n (the probability that a bank that made an innovative loan will be able to refinance at $t=1$).

Rearranging this equation yields

$$1+r_0=\frac{1+r}{\lambda_s\delta_s+\lambda_n\delta_n}. \tag{17}$$

Next, I determine the interest rate the bank can charge the borrower on an innovative loan. There are two states to consider: when $N_n\ge J$, and when $N_n<J$.

When $N_n\ge J$, the number of banks, N_n, that drew the belief that $p_n=p$ exceeds the number of borrowers seeking innovative loans, i.e., loan supply exceeds loan demand. When $N_n<J$, loan demand exceeds supply. I can now establish the following result

Lemma 2. At $t=0$, if $N_n\ge J$, the loan interest rate r_L^n is such that the borrower's repayment obligation to the bank at $t=2$, $[1+r_L^n]$, is set to yield the bank a zero expected profit. If $N_n<J$, then it is a Nash equilibrium for every borrower's repayment obligation to be set at X, the maximum income the borrower can pledge to the bank, and this Nash equilibrium is unique if R_n-X is large enough.

Consider first when $N_n\ge J$. In this case, the innovative loan market is perfectly competitive, so r_L^n is set to yield the bank zero expected profit.

Table 1
Summary of states at $t=1$.

State	Probability of state for bank that invested in standard loan	Probability of state for bank that invested in innovative loan	Outcome
1. Investors draw $p_n=p$ and observe $\phi=s$	$\rho\overline{\gamma}$	$\rho[1-\gamma(\rho)]$	Second period funding provided at $r_1^s(p)$
2. Investors draw $p_n=p$ and observe $\phi=n$	$\rho[1-\overline{\gamma}]$	$\rho\ \gamma(\rho)$	Second period funding provided at $r_1^n(p)$
3. Investors observe $p_n=0$ and observe $\phi=s$	$[1-\rho]\overline{\gamma}$	$[1-\rho][1-\gamma(\rho)]$	Second period funding provided at $r_1^s(0)$
4. Investors observe $p_n=0$ and observe $\phi=n$	$[1-\rho][1-\overline{\gamma}]$	$[1-\rho]\gamma(\rho)$	Second period funding denied

A bank that has made an innovative loan views the probability of having its short-term financing renewed in the second period as δ_n (see Eq. (15)). Thus δ_n is the probability that the bank will continue until $t=2$ and p is the probability that the borrower will repay the entire loan obligation $1+r_L^n$. The bank's zero-profit condition can be written as:

$$p\delta_n[1+r_L^n]-\mathrm{E}[1+\hat{k}_e]-p[1-E][1+r_0]G(\rho)=0, \tag{18}$$

where the expected cost of financing, conditional on second-period funding being renewed, is

$$G(\rho)\equiv\rho[1-\gamma(\rho)]r_1^s(p)+\rho\gamma(\rho)r_1^n(p)+[1-\rho][1-\gamma(\rho)]r_1^s(0). \tag{19}$$

To interpret Eq. (18), note that the bank obtains its repayment of $[1+r_L^n]$ from the borrower with probability $p\delta_n$, for an expected payoff of $p\delta_n[1+r_L^n]$. From this, one must subtract the bank's cost of equity, $\mathrm{E}[1+\hat{k}_e]$, and its expected cost of debt financing. The expected debt financing cost is the amount of debt raised at $t=0$, $[1-E]$, times the promised repayment to the first-period creditors per dollar of debt financing, $[1+r_0]$, times the expected amount to be paid to second-period creditors to roll over the first-period debt, $G(\rho)$, times the probability that repayment will be made to the creditors, p.

Solving Eq. (18) yields

$$1+r_L^n=\frac{E[1+\hat{k}_e]+p(1-E)[1+r_0]G(\rho)}{p\delta_n}. \tag{20}$$

Now consider the case in which $N_n<J$. Given that the borrower's repayment is $X>1+r_L^n$, it follows that this satisfies the bank's participation constraint. Denote π_b^0 as the bank's assessment of its expected profit when $N_n\geq J$ and π_b^+ as the bank's assessment of its expected profit when $N_n<J$ and the bank draws $p_n=p$. Then, it follows that $\pi_b^0=0$ and $\pi_b^+>0$.

3.2.2. The bank's decision to participate in the innovative loan market

I now examine the bank's participation in the innovative loan market conditional on its belief about p_n. If the bank believes $p_n=p$, then the bank assesses its expected profit as

$$\pi_b^+(\rho,\rho^*)=p\delta_n(\rho)X-E[1+\hat{k}_e]-p[1-E][1+r_0]G(\rho,\rho^*). \tag{21}$$

To interpret Eq. (21), note that this expected profit is calculated for the case in which the innovating bank earns monopoly rents on its innovation. This consists of its expected payoff on the loan, $p\delta_n(\rho)X$, which is the probability the loan will repay (p) times the promised repayment (the maximum pledgeable repayment, X) times the probability the loan can be refinanced at $t=1$ (which is $\delta_n(\rho)$). From this are subtracted the cost of equity, $E[1+\hat{k}_e]$, and the expected cost of debt, $p[1-E][1+r_0]G(\rho,\rho^*)$.

Now the expected cost of debt (writing the various interest rates as functions of the equilibrium agreement parameter) is

$$\begin{aligned}G(\rho,\rho^*)=&\rho[1-\gamma(\rho)]r_1^s(p,\rho^*)+\rho\gamma(\rho)r_1^n(p,\rho^*)\\&+[1-\rho][1-\gamma(\rho)]r_1^s(0,\rho^*),\end{aligned} \tag{22}$$

where ρ^* is the bank's equilibrium choice of ρ, $r_1^n(p,\rho^*)$ is given by Eq. (12) with ρ^* substituted in λ_s^n, $r_1^s(p,\rho^*)$ is given by Eq. (13) with ρ^* substituted in λ_s^s, and $r_1^s(0,\rho^*)$ is given by Eq. (9) with ρ^* substituted in λ_s^s. Because investors cannot observe the bank's choice of ρ, the various debt funding costs are based on investors' expectations about the bank's choice of ρ. In equilibrium, these expectations must be correct, so these costs must be based on ρ^*. The bank cannot influence these costs through its actual choice of ρ (see, for example, Milbourn, Shockley, and Thakor, 2001). Only the various probabilities—δ and the probabilities embedded in G—depend on the bank's actual choice of ρ. G depends on both ρ and ρ^* because the interest costs in G depend on ρ^* and the probabilities of these costs depend on ρ. Thus, $G(\rho,\rho^*)$ is the sum of three interest rates, $r_1^s(p,\rho^*)$, $r_1^n(p,\rho^*)$, and $r_1^s(0,\rho^*)$, each multiplied by the probability of occurrence of the state in which it applies (these are the three states in Table 1 in which the bank is able to get second-period refinancing).

If the bank draws $p_n=0$ at $t=0$, then investing in the innovative loan yields an expected profit of $-E[1+\hat{k}_e]$. Thus, a standard loan is preferred in this case.

Lemma 3. Any bank drawing $p_n=p$ prefers to invest in the innovative loan, and any bank drawing $p_n=0$ prefers to invest in the standard loan.

3.3. Analysis of the standard loan market

Because the events at $t=1$ in this market are identical to those for the innovative loan market, only events at $t=0$ are examined.

The cost of debt financing for the bank at $t=0$, $1+r_0$, is the same as before because at $t=0$ investors cannot tell whether the bank invested in a standard or an innovative project. Assume for now (to be verified later) that $N>J+M$. This ensures that the market for standard loans is always perfectly competitive. Thus, the interest rate on the standard loan, r_L^S, is set to yield the bank a zero expected profit.

4. Overall equilibrium at $t=0$

In this section I combine the innovative and standard loan markets to examine the innovative bank's choice of the innovation-familiarity measure, ρ, in equilibrium. I then examine the endogenous determination of N. I conclude with the main result of the paper about the conditions under which a crisis occurs.

4.1. The determination of ρ at $t=0$

Assume $N>J+M$. Given the number of banks in the industry, N, the lead innovator bank chooses ρ to maximize its expected profit, i.e.,

$$\underset{\rho\in[0,1]}{\mathrm{Max}}\ \theta[1-\beta_J]\pi_b^+ \tag{23}$$

because its expected profit from an innovative loan conditional upon $N_n>J$, as well as its expected profit from a standard loan, is zero at every level of ρ chosen by the bank. Recall that π_b^+ is given in Eq. (21).

Defining $U(\rho^*,\rho) \equiv \theta[1-\beta_J(\rho)]\pi_b^+(\rho^*,\rho)$, the bank's problem can be written as

$$\underset{\rho\in[0,1]}{\text{Max}}\, U(\rho^*,\rho) \tag{24}$$

In equilibrium, the bank's solution to Eq. (24), call it ρ, satisfies $\rho=\rho^*$. It is assumed throughout that X is large enough to satisfy the bank's participation constraint at any ρ such that Eq. (18) is satisfied.

Now, the first-order condition that ρ must satisfy is

$$-[\partial\beta_J/\partial\rho]\pi_b^+(\tilde{\rho},\rho^*)+[1-\beta_J][\partial\pi_b^+/\partial\rho]=0, \tag{25}$$

where

$$\partial\pi_b^+/\partial\rho = p[\partial\delta_n(\rho)/\partial\rho]X - p[1-E][1+r_o][\partial G/\partial\rho], \tag{26}$$

and

$$\begin{aligned}\partial G/\partial\rho &= \{1-\gamma(\rho)-\rho\gamma'(\rho)\}r_1^s(p)+[\gamma(\rho)+\rho\gamma'(\rho)]r_1^n(p)\\ &\quad -\{1-\gamma(\rho)+\gamma'(\rho)[1-\rho]\}r_1^s(0)\\ &= [1-\gamma(\rho)-\rho\gamma'(\rho)][r_1^s(p)-r_1^s(0)]\\ &\quad +\gamma(\rho)r_1^n(p)-\gamma'(\rho)[r_1^s(0)-\rho r_1^n(p)].\end{aligned} \tag{27}$$

Moreover,

$$\begin{aligned}\partial\delta_n(\rho)/\partial\rho &= 1-[1-\gamma(\rho)]-[1-\rho]\gamma'(\rho)\\ &= \gamma(\rho)-[1-\rho]\gamma'(\rho) > 0 \quad \text{because } \gamma'(\rho)<0.\end{aligned} \tag{28}$$

Lemma 4. The optimal $\tilde{\rho}$ satisfying the first-order condition Eq. (25) *also satisfies the second-order condition for a unique maximum.*

Lemma 5. The bank's optimal choice, ρ, is strictly decreasing in X, the maximum pledgeable portion of the borrower's loan.

The intuition is that the higher is X, the higher is the bank's expected profit, conditional on other banks not mimicking its innovation. This makes it more attractive for the bank to make the innovation less familiar and reduce the probability of competitive entry.

Theorem 1. There exists at least one equilibrium choice of ρ, which is $\rho^*\in(0,1)$. That is, the bank chooses in equilibrium $\rho=\rho^*<1$. Moreover, $\theta[1-\beta_J]\pi_b^+(\rho^*,\rho^*)>0$.

The intuition is as follows. The bank's problem in Eq. (23) is concave in ρ, so the bank's optimal choice, ρ, is an interior solution and it is uniquely determined by the first-order condition (25) for a given ρ^*. The key is that $\rho^*<1$. The intuition for this is that only by setting $\rho^*<1$ can the lead innovator ensure that $\beta_J<1$. Because $\beta_J=1$ at $\rho=1$, by setting $\rho^*=1$ the bank would guarantee itself zero expected profit, whereas $\rho^*<1$ generates positive expected profit. Moreover, $\rho^*=0$ cannot be an equilibrium either because then the bank is guaranteed lack of access to second-period financing with probability one, in which case its expected profit is again zero.

4.2. The determination of N at t=−1

Recall that the cost of entry into the banking system is $C>0$. The result below shows that the bank's expected profit is decreasing in N and that, ignoring C, a positive expected profit is possible even with $N>J+M$. Clearly, the equilibrium number of banks entering the industry is such that each bank's expected profit exactly equals C. From this, the following result follows.

Theorem 2. For $C>0$ low enough, the number of banks entering the industry, N, satisfies $N>J+M$.

Given that $N>J+M$, there is an equilibrium in which banks earn zero expected profits on standard loans because the number of banks competing for these loans is at least M. This is because if N_n were sufficiently greater than J, so that there were fewer than M banks competing for standard loans, there would be zero expected bank profits for innovative loans and positive expected bank profits for standard loans. But this cannot be an equilibrium, because as many as N_n-J banks could shift from innovative to standard loans, driving down the expected bank profits on standard loans to zero while keeping expected bank profits on innovative loans also at zero. Further, despite $N>J+M$, a bank can expect to earn positive expected profits in the innovative loan market, ignoring the cost of entry.

It is useful now to introduce a definition. Consider two functions $\gamma_1(\rho)$ and $\gamma_2(\rho)$ such that $\gamma_1(\rho)>\gamma_2(\rho)$, $\forall\rho\in(0,1)$, $\gamma_1(0)=\gamma_2(0)=1$, and $\gamma_1(1)\equiv\overline{\gamma}_1>\overline{\gamma}_2\equiv\gamma_2(1)$. Then, the definition is that $\gamma_1(\rho)$ "dominates" $\gamma_2(\rho)$. That is, for every $\rho>0$, the γ_1 function is associated with a more informative signal of the bank's portfolio than the γ_2 function. The following result can now be proved.

Theorem 3. Assume that the borrower's pledgeable income $X\in[\underline{X},\overline{X}]$, and consider two functions γ_1 and γ_2 such that γ_1 dominates γ_2. Then, in any equilibrium, the probability of a crisis in which the majority of banks are denied credit is positive. The equilibrium with γ_2 involves less familiar innovation than the equilibrium with γ_1.

The intuition for this result is as follows. Because of an entry cost into banking, entry must be such that some positive level of post-entry expected profit can be earned. Earning positive bank profits on standard loans is not possible as long as the number of entering banks is large enough to fully satisfy standard loan demand, because all banks view standard loans the same way and all of them compete for these loans. But with innovative loans, even when there are enough banks that can potentially supply credit in sufficient quantity for loan supply to exceed loan demand, the actual number of banks participating in the market can be such that loan demand exceeds supply. This enables banks to earn positive expected profits in this market and generates an incentive for banks to innovate.

Expected profits from innovation are, however, decreasing in the number of competing banks, so the innovating bank has an incentive to come up with an innovation that is so unfamiliar that relatively few banks are likely to imitate. While this increases expected profits conditional on investors providing debt financing to the bank for the second period, the probability that banking sector investors will withdraw their funding of the bank after the first period also goes up as the innovation becomes less familiar. The bank thus faces a trade-off

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between the higher profit from greater innovation (lower innovation familiarity) and the higher accompanying risk of losing second-period funding. It chooses in equilibrium an innovation that has a probability of being imitated by all banks that is less than one and a probability of investors not funding the bank for a second period that is greater than zero.

The intuition for why there is less familiar innovation when one moves from a function γ_1 to a dominated function γ_2 is as follows. Because $\gamma_2(\rho) < \gamma_1(\rho)\ \forall \rho \in (0.1]$, and because it has already been established that $\rho^* \in (0,1)$, it follows that for any ρ^*, the bank that adopts the innovation will perceive a lower probability that it will be denied second-period funding with γ_2 than with γ_1 (see Table 1). This pushes the lead innovator to adopt a less familiar innovation in the equilibrium with γ_2 than in the equilibrium with γ_1. Further, since $\overline{\gamma}_2 < \overline{\gamma}_1$, the probability that a bank making a standard loan will be mistakenly denied second-period funding is also higher with γ_2 than with γ_1. Thus, greater opacity of information available to investors could lead to both greater innovation and a higher probability of a financial crisis.[16] This means banks will choose more innovative (in the sense of being less familiar) financial products when their asset portfolios are more opaque to investors. In other words, the opacity of the information available to investors strengthens the financial innovation incentives of banks.

4.3. *Key features of the model and their roles*

The model has four features that are important for the results. To appreciate the roles of these features, I summarize the intuition and explain how each feature of the model contributes to the intuition along the way.

First, banks operate in a competitive banking system in which their expected profits are decreasing in the number of banks they are competing with. This means that standard loans, on which all competitors agree on the default probabilities, produce zero expected profit for each bank due to unrestricted competition.

Second, the bank is allowed to choose between a standard loan and an innovative loan, but innovation cannot be patent-protected. The lack of patent protection makes it relatively easy for innovations to be imitated, which then leads to correlated innovations and hence greater systemic risk. Moreover, innovative loans are subject to potential disagreement over the likelihood of default. This disagreement means that not all banks will adopt the innovation introduced by the lead innovator, and hence only limited competition will emerge in the innovative loan market. In fact, by choosing the "familiarity" for the innovative loan, the lead innovator can determine how competitive the innovative loan market will be. Choosing a less familiar innovation leads to less competition and higher expected profits, and in the absence of patent protection for innovations, reducing the familiarity of the innovation is the only way to reduce competition from other banks. That is, the need for innovation to involve potential disagreement through lack of familiarity is a natural consequence of the absence of patent protection for financial innovation.

The counterbalance to this propensity to seek the most unfamiliar innovation is that banks face refinancing risk. This risk arises from the third and fourth features of the model. The third feature is that a less familiar innovation is also more likely to generate disagreement by financiers and hence cause second-period investors to not wish to provide funding to roll over the first period debt for banks that have made innovative loans. The investors' refinancing decision is based on noisy signals they receive about the profitability of the innovative loan and each bank's portfolio composition.

Banks would not be concerned about post-lending investor disagreement if they could match the maturities of their assets and liabilities. This is where the fourth feature, and one that has been suppressed in the main model to focus on the core intuition, comes in. It is that banks face refinancing risk due to maturity mismatching. That is, each bank makes a two-period loan that is financed with one-period (uninsured) debt that needs to be rolled over to permit the bank to continue until loan maturity. In the extension of the model in Appendix A where this debt maturity is endogenized, the relevant assumption is that moral hazard exists in the bank's provision of effort to monitor the loan and that this effort must be provided in each period. This moral hazard is what gives rise to the need for short-term debt funding for market discipline that guarantees the desired monitoring in each period but also makes the bank susceptible to debt funding being prematurely cut off (e.g., as in Calomiris and Kahn, 1991).

Short-term debt can also be rationalized in other ways. For example, Brunnermeier and Oehmke (2010) show that an individual creditor could have an incentive to shorten the maturity of its own loan to the bank, so that, conditional on adverse information, it has the opportunity to pull out before other creditors can. They argue that this can lead to a "maturity rat race" among creditors that can expose banks to excessively high refinancing risk.

5. Welfare analysis and the regulatory policy implications

The purpose of this section is to conduct a welfare analysis and examine possible regulatory interventions to improve welfare. Typically in a model with disagreement and multiple rational beliefs, it is not possible to unambiguously determine the socially optimal level of innovation because one cannot ascertain a priori whose beliefs are correct. Nonetheless, under some assumptions, welfare analysis can be conducted from an ex ante perspective before beliefs are drawn. For the welfare analysis, suppose that the feasible range of innovation is described by $[0,\rho_{max}]$, where $\rho_{max} \in (0,1)$ is sufficiently high so that $\rho_{max} > \rho^*$ and the lead innovator's optimal choice, ρ^*, is not constrained by ρ_{max}. Moreover, assume that the social planner believes ex ante that any innovation introduced

[16] While this is plausible conjecture, a comparison of crises probabilities across two equilibria is complex because γ_2 induces the innovator to adopt a less innovative product but at the same time exposes standard-product banks to greater refinancing risk.

by the lead innovator is a good innovation.[17] Then the (benevolent) social planner's objective function can be written as

$$\underset{\rho \in [0,\rho_{max}]}{\text{Max}} L \equiv \theta[pR_n - p_s R]E(N_n^0 | \rho), \tag{29}$$

where $E(N_n^0|\rho)$ is the expected number of banks that pursue the innovation (conditional on the chosen ρ) and are able to continue with it until $t=2$ to realize the expected payoff of pR_n, θ is the probability that the lead innovator draws a belief $p_n = p$ (and hence introduces the innovation), and $pR_n - p_s R$ is the incremental economic gain from introducing the innovation relative to the standard loan (which is the difference in the expected values of the innovative and standard loans when the innovation is deemed as being good). It will be assumed that $pR_n - p_s R > C$, so that the incremental economic gain from the innovation exceeds the entry cost borne by the marginal bank pursuing the innovation. Hence, maximizing (29) is equivalent to maximizing a welfare function that takes C into account. The expression for $E(N^0|\rho)$ is provided in the proof of Theorem 4 in Appendix B. The following result can now be stated.

Theorem 4. The socially-optimal degree of innovation involves the social planner setting ρ_S^* that exceeds the lead innovator's private optimum, ρ^*.

The intuition for this result is as follows. For the social planner, what matters is the total surplus created by a good innovation (relative to no innovation), which is $pR_n - p_s R > 0$, and not how this surplus is shared between the borrower, the bank, and the (debt) investors. Thus, when a good innovation is introduced, the social planner wishes to minimize the likelihood that the innovation will not be prematurely liquidated due to innovating banks being unable to refinance at the end of the first period, i.e., minimize the likelihood of a crisis. Moreover, because the surplus per innovation is positive, the social planner also wishes to maximize the expected number of banks adopting the innovation, subject to the constraint that the expected profits from innovation adoption are high enough to cover the entry costs of follower banks. The probability that an innovating bank will be refinanced is increasing in the familiarity of the innovation, and the expected number of banks that adopt the innovation and survive until $t=2$ is increasing in the familiarity of innovation as long as the innovation is not so familiar that the expected profits from innovation adoption fall below C for follower banks. So the social planner's optimum favors a relatively high ρ.

By contrast, the lead innovator does not care about the social surplus of the innovation, but just the expected innovation rent it can extract. This rent depends on the number of other banks that will also adopt the innovation and the refinancing risk. While the innovating bank's interest and the social planner's interest overlap when it comes to the desire to reduce refinancing risk (which pulls them both in the direction of choosing a higher ρ), these interest diverge when it comes to the number of banks that adopt the innovation. The lead innovator wants to minimize this number, whereas the social planner wants to maximize it. This is why the private and social optima diverge and the private optimum involves a higher degree of innovativeness or a lower degree of familiarity than what is socially optimal.

Given that the private optimum involves a lower ρ than the social optimum, what can a bank regulator do? Would higher capital requirements help? The answer is possibly yes. To see this, note first that shareholders are unwilling to provide funding at $t=0$, unless there is single-period debt financing creating the necessary market discipline. But, conditional on the initial availability of equity, and assuming that additional equity could be unavailable at $t=1$ (say due to debt overhang), higher equity capital makes the bank perceive a higher expected cost associated with being unable to refinance with debt at $t=1$. From the bank's first-order condition, (25), one can see that this induces the lead innovator to choose a lower degree of innovation (higher ρ). It also induces more banks to pursue the innovation.[18] Hence, the private optimum moves closer to the social optimum when banks are subject to higher capital requirements.

Consider now the issue of information disclosure requirements that increase the transparency of banks' balance sheets, i.e., increase $\gamma(\rho)$ for every ρ. As shown in Theorem 3, greater transparency makes a higher degree of innovation *less* attractive to the lead innovating bank. Thus, greater informational transparency reduces the innovativeness of financial products but makes the innovation more pervasive. This, in turn, means that the likelihood that any given innovating bank will be unable to refinance is lower, but more innovating banks face significant refinancing risk.

What is the effect of government intervention? Suppose investors were to decide not to provide funding at $t=1$ and the government were to intervene by providing public funds. Clearly, the crisis would be gone. But banks would then rationally assess at $t=0$ that a positive probability exists that public funds will replace private funds at $t=1$ in the event of a crisis. This reduces the ρ chosen by the lead innovator. Hence, the new products introduced become more innovative and less familiar as the likelihood of a government bailout increases.

A greater likelihood of government intervention thus increases the level of privately-optimal innovation and possibly raises the probability of occurrence of a crisis. Suppose now that, instead of assuming that the social planner always agrees with the lead innovator when it comes to determining what is a good innovation, one assumes that some objective reality reveals which

[17] This assumption is not crucial. All of the subsequent analysis holds if the social planner believes that she will agree with the lead innovator with probability $\xi(\rho)$, with $\xi' \geq 0$ and $\xi(\rho)pR_n > p_s R$ for ρ high enough in $[0,\rho_{max}]$.

[18] If one thinks of a crisis as the result of the realization of adverse tail risks, then the empirical evidence does suggest that higher capital helps banks to better withstand extremely adverse conditions and lowers the probability of a crisis. See De Jonghe (2010). Berger and Bouwman (2011) show empirically that higher pre-crisis capital improves a bank's odds of surviving a crisis.

innovations are good or socially efficient ($p_n = p$) and which are not ($p_n = 0$) and that lead innovators sometimes pick good innovations and sometimes bad innovations, but the likelihood of the innovation being good is increasing in ρ. That is, innovators are likely to make fewer errors with more familiar innovations. Then, government bailouts could increase the odds of bad innovations being introduced at $t=0$ (due to the ex ante incentive effect of lowering ρ) and also the probability that such innovations will survive at $t=1$ (due to the ex post effect of the bailout). In other words, ex post bailouts can reduce the beneficial ex ante effects of raising capital requirements.

6. Conclusion

In this paper, I develop a model that delivers a simple result: competitive banking systems without patent protection for innovations are inherently susceptible to financial crises. This result arises primarily from the financial innovation incentives of financial institution that rely on disagreement as a de facto entry barrier to protect profit margins on innovative products.

The analysis generates some empirical predictions. First, the more competitive the financial system (the lower the cost of entry), the stronger are financial innovation incentives and the greater is the amount of innovation. Second, more innovative financial systems are more prone to financial crises. Taken together, these two results provide a new perspective on the role of financial market competition in the occurrence of crises. Third, greater transparency about the balance sheets of financial institutions can also depress innovation as the higher the likelihood of an ex post financial crisis makes innovative loans less profitable for banks. Thus, some opaqueness in financial institutions' balance sheets may be necessary for financial innovation.[19] This has social value implications because a good innovation ($p_n = p$) in this analysis adds value to the economy.

Appendix A. Endogenizeng the short-term nature of bank debt and bank capital structure

To focus on the core intuition of the model, thus far it has been simply assumed that banks finance themselves with a mix of short-term debt and equity. In this Appendix, these features are endogenized, so that it can be seen how they interact with the core features of the model. To do this, some additional assumptions are introduced.

A.1. Assumptions

Bank's effort choice and project payoff distribution: To have a positive success probability, the bank needs to expend effort $e_0 = e$ at $t=0$ and $e_1 = e$ at $t=1$, where $e_i \in \{e,0\} \forall\ i=1.2$, and $e>0$. That is, if the bank chooses $e_0 = e$ in the first period (at $t=0$), and $e_1 = e$ in the second period (at $t=1$), the success probability of the loan is positive. If the bank chooses either $e_0 = 0$ or $e_1 = 0$, the success probability of the loan is zero, implying that the loan pays off zero almost surely, whether it is a standard or an innovative loan. One can think of the bank's effort choices as being related to the due diligence of the bank in credit analysis and loan monitoring to ensure that the borrower stays on track to repay the loan. It can be viewed as a shorthand way of formalizing the value added by the bank in the intermediation process. The (private) cost to the bank of choosing e is $\Psi > 0$.

The bank's effort choices are costlessly observable to all but not contractible. Moreover, human capital is inalienable (see Hart and Moore, 1994), so the bank cannot credibly precommit to making a particular effort choice.

The probability of success of the standard loan is thus $p_S \in (0,1)$, conditional on the bank choosing $e_0 = e_1 = 1$. The probability of successes of the innovative loan is $p_n \in (0,1)$, conditional on bank choosing $e_0 = e_1 = 1$.

Availability of private-benefit loan to bank: In addition to standard and innovative loans, each bank has access to a "private-benefit" loan, which requires a \$1 investment at $t=0$ and gives the bank manager a private benefit of $B>0$ but produces a zero cash flow almost surely for investors and shareholders of the bank at $t=2$. Assume $B<1$, so the project is socially inefficient. Which loan the bank has invested in at $t=0$ (standard, innovative or private-benefit) is known privately only to the bank at $t=0$.

Investors: The bank chooses $e_0 \in \{e,0\}$ at $t=0$ after it knows which borrower it is dealing with. Investors observe the bank's choice of e_0 and decide whether to provide financing.

If investors are willing to provide second-period funding to the bank based on their beliefs p_n and their signal ϕ, the bank chooses $e_1 \in \{e,0\}$. Investors observe e and decide whether to extend second-period funding.

A.2. Analysis: innovative loan market

Events at $t=1$: The following result is immediate.

Lemma 6. Whether the bank made an innovative or a standard loan at $t=0$*, it will invest* $e_1 = e$ *at* $t=1$.

The idea is simple. Because e_1 is observable to investors, the bank cannot secure second-period financing unless it chooses $e_1 = e$.

Events at $t=0$: First examine how investors ensure that the bank will not invest in the socially-inefficient private-benefit project. This is done by investors funding the bank only if it posts equity capital of at least E, where E satisfies the incentive compatibility (IC) constraint:

$$B - E[1+k_e]^2 \le 0. \tag{30}$$

Note that the IC constraint is written like this because if the bank makes an innovative or a standard loan for which loan supply exceeds demand (and this happens in

[19] Another complication, and one that is consistent in spirit with our assumption of partial bank portfolio opacity, is that bank portfolios are quite diversified. A recent theory shows that while diversification reduces individual bank risk, it increases systemic risk. See Wagner (2010).

some states), the bank's expected profit is zero. Because this constraint holds tightly in equilibrium, we can solve for E[20]:

$$E=B/[1+\hat{k}_e] \tag{31}$$

where $[1+\hat{k}_e]\equiv[1+k_e]^2$.

It is assumed that B is large enough to ensure that $1+r_L^n$ in Eq. (20) exceeds the $\underline{X}$ in Eq. (10).

A condition that is necessary for investors to provide funding at $t=0$ is that the bank chooses $e_0=e$. Thus, I have the following.

Lemma 7. The bank chooses $e_0=e$ at $t=0$ regardless of whether it is making an innovative or a standard loan. Moreover, debt investors are willing to provide debt financing only if the bank posts equity of $E=B[1+\hat{k}_e]^{-1}$, and in this case, they provide only single-period debt financing at $t=0$ that explicitly needs to be replaced at $t=1$ by new one-period debt financing for another period. Shareholders willing to provide equity at $t=0$ only if the bank is also raising single-period debt financing.

The reason that debt financing is available only as short-term debt is the inalienability of the bank's human capital in performing due diligence on the loan. If debt investors provide two-period financing, the bank chooses $e_1=0$ at $t=1$, thereby making the creditors' claims worthless. Thus, investors must reserve the right to observe e_1 before extending second-period credit. Similarly, shareholders extend (long-term) financing only if they can rely on the market discipline provided by short-term creditors, which ensures $e_1=e$. Thus, in this model, debt and equity complement each other and neither source of financing is accessible to the bank without the other.

It has been assumed that $k_e>r$, i.e., the cost of equity exceeds that of debt. The role of this assumption is to ensure that the bank issues only as much equity as is necessary to guarantee incentive compatibility and make investors be willing to provide debt financing. That is, equity, E, is given by Eq. (31). If it were assumed instead that $k_e=r$, then the bank prefers equity to short-term debt because with equity there is no refinancing risk. However, all-equity financing is not feasible because the market discipline of short-term debt is necessary to make investors be willing to purchase equity. Thus, if there was a (small) cost to investors of monitoring the bank's effort choice in each period, then there will exist a minimum debt level, say D_{min}, such that debt monitoring will occur if $D\geq D_{min}$, and the bank will finance with D_{min} in debt and the rest in equity.

[20] It will be verified that there will be some states, with aggregate probability that is positive, in which the bank will earn exactly zero expected profit. In these states, E will be the amount of capital needed for incentive compatibility. There will also be states in which the bank earns a positive expected profit, and the right-hand side of Eq. (10) will be positive, so that the E needed for incentive compatibility will be smaller than that in Eq. (11). But the E in Eq. (11) will be sufficient for incentive compatibility in all states.

Appendix B. Determination of $r_d^1(0)$, interest rate on bank's new one-period debt at $t=1$, conditional on $p_n=0$ (Eq. (2))

$$\frac{1}{N}\left\{\{A_1\}p_s\left[1+r_d^1(0)\right]+\{A_2\}\{0\}\right\} + \left[\frac{N-1}{N}\right]\left\{\{A_3\}p_s\left[1+r_d^1(0)\right]+\{A_4\}\{0\}\right\}=1+r, \tag{32}$$

where $1/N$=probability this bank was the lead innovator at $t=0$.

$$A_1\equiv \underbrace{[1-\theta]}_{\text{probability the bank drew } p_\ell} + \underbrace{\theta}_{\text{probability the bank drew } p_h} \underbrace{\left[1-\frac{J}{N_n}\right]}_{\text{probability the bank did not participate in innovative loan}} \underbrace{\beta_J}_{\text{probability innovative loan supply exceeded demand}}, \tag{33}$$

$$A_2\equiv \underbrace{\theta}_{\text{probability bank drew } p_h} \underbrace{[J/N_n]}_{\text{probability bank made innovative loan}} \underbrace{\beta_J}_{\text{probability innovative loan supply exceeded demand}} + \underbrace{[1-\beta_J]}_{\text{probability innovative loan demand exceeded supply}}. \tag{34}$$

$(N-1)/N$=probability this bank was not the lead innovator at $t=0$

$$A_3\equiv \underbrace{[1-\theta]}_{\text{probability lead innovating bank drew } p_\ell} + \underbrace{\theta[1-q]}_{\text{probability lead innovating bank drew } p_h \text{ but this bank drew } p_\ell} + \underbrace{\theta q}_{\text{probability lead innovating bank drew } p_h \text{ and this bank drew } p_h} \underbrace{\left\{\left[1-\frac{J}{N_n}\right]\right.}_{\text{probability that this bank did not participate in innovative loan market}} \underbrace{\left.\beta_J\right\}}_{\text{probability loan supply exceeded demand}}, \tag{35}$$

$$A_4\equiv \underbrace{\theta q}_{\text{probability lead innovating bank drew } p_h \text{ and this bank drew } p_h} \underbrace{[J/N]}_{\text{probability this bank participated in innovative loan market}} \underbrace{\beta_J}_{\text{probability loan supply exceeded demand}} + \underbrace{[1-\beta_J]}_{\text{probability loan demand exceeded supply}}. \tag{36}$$

I can thus write $\lambda_s\equiv A_1N^{-1}+A_3[N-1]N^{-1}$ as the probability (as assessed by investors) that the bank made a standard loan. Similarly, I can write $\lambda_n\equiv A_2N^{-1}+A_4[N-1]N^{-1}$ as the probability that the bank made an innovative loan.

The expression above recognizes that investors have to first assess whether the bank they financed was the lead innovator or not, recognizing that each of the N banks had an equal probability $1/N$ of being the lead innovator. Then, investors have to assess the probability that the bank actually made an innovative loan and the probability that it made a standard loan. The probability of a standard loan is multiplied by $p_s[1+r_d^1(0)]$, which is the expected value at $t=1$ of the investors' payoff at $t=2$ with a standard

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loan. Similarly, the probability of an innovative loan is multiplied by $p_\ell[1+r_d^1(0)]$, which is the present value at $t=1$ of the investors' payoff at $t=2$ with an innovative loan to which investors attach a success probability of p_ℓ. Because $p_\ell=0$, this term drops out.

Proofs

Proof of Lemma 1. Follows from the fact that Eq. (8) and (10) hold, and the discussion in the text. □

Proof of Lemma 2. Suppose first that $N_n \geq J$. Then loan supply exceeds loan demand. The conjectured Nash equilibrium is that every borrower offers to pay r_L^n, where r_L^n is given by Eq. (20). Suppose a bank demands $\hat{r}_L > r_L^n$. Then it is clear that no borrower wishes to take credit from that bank because credit is available at a lower price elsewhere. So it is a Nash equilibrium for all banks to charge r_L^n, and it is easy to see that this Nash equilibrium is unique.

Now suppose $N_n < J$. In the conjectured equilibrium, all borrowers offer to pay X, their maximum pledgeable income, as repayment on the loan. Suppose a borrower offers to pay $y<X$. Then no bank agrees to extend credit to that borrower because banks can make higher expected profits elsewhere. The borrower thus gets rationed almost surely, loses its entire expected surplus from the project, $p[R_n-X]$, and ends up with a payoff of zero. By contrast, if the borrower offers to repay X, its expected payoff is $[N_n/J]p[R_n-X]>0$. Similarly, no bank has an incentive to charge less than X because the only effect of this is to lower its expected profit without increasing the probability of making an innovative loan. This probability is already one for every participating bank. No bank wishes to charge more than X either, because this exceeds the borrower's maximum pledgeable income. Thus, a repayment of X is a Nash equilibrium.

Another Nash equilibrium could also exist at $X-\varepsilon$, where $\varepsilon>0$ is a small positive scalar. That is, suppose all borrowers offer $X-\varepsilon$. A borrower that offers $X-\varepsilon$ has a probability N_n/J of getting credit. But if a borrower defects by offering X, its probability of getting credit is one. Is

$$\left[\frac{N_n}{J}\right][R_n-\{X-\varepsilon\}] > 1[R_n-X]? \tag{37}$$

That is,

$$\varepsilon\left[\frac{N_n}{J}\right] > [R_n-X]\left[1-\frac{N_n}{J}\right]? \tag{38}$$

Now the maximum value that N_n/J can take before hitting the perfect-competition case is $N_n/J=(J-1)/J$. So is

$$\varepsilon\left[\frac{J-1}{J}\right] > [R_n-X]\left[1-\frac{[J-1]}{J}\right]? \tag{39}$$

If this inequality holds, then offering $X-\varepsilon$ is a Nash equilibrium as no borrower wishes to defect with an offer of R_n-X. So, to preclude this Nash equilibrium, it is sufficient that $\varepsilon[J-1]<[R_n-X]$, which holds if R_n-X is sufficiently high. Thus, R_n high enough ensures that a repayment of X is a unique Nash equilibrium. □

Proof of Lemma 3. Conditional on $p_n=p$, the bank's expected profit from an innovative loan is $[1-\beta_J]\pi_b^+>0$. Because $N>M+J$, the expected profit from a standard loan is zero. Thus, a bank drawing $p_n=p_h$ prefers an innovative loan to a standard loan.

Conditional on $p_n=0$, the bank's expected profit on an innovative loan is $\pi_b^- \leq 0$. Thus, the bank prefers a standard loan in this case. □

Proof of Lemma 4. The second-order condition for a unique maximum is:

$$\begin{aligned} SOC \equiv &-[\partial^2\beta_J/\partial\rho^2]\pi_b^+(\tilde{\rho},\rho^*)-[\partial\beta_J/\partial\rho][\partial\pi_b^+/\partial\rho] \\ &-[\partial\beta_J/\partial\rho][\partial\pi_b^+/\partial\rho]+[1-\beta_J][\partial^2\pi_b^+/\partial\rho^2]<0. \end{aligned} \tag{40}$$

Now

$$\partial^2\pi_b^+/\partial\rho^2 = p[\partial^2\delta_n/\partial\rho^2]X-p[1-E][1+r_0][\partial^2 G/\partial\rho^2], \tag{41}$$

where

$$\partial^2\delta_n/\partial\rho^2 = 2\gamma'-[1-\rho]\gamma''<0 \quad \text{because } \gamma'<0,\ \gamma''>0. \tag{42}$$

$$\begin{aligned} \partial^2 G/\partial\rho^2 &= -2\gamma'[r_1^s(p)-r_1^s(0)]+2\gamma' r_1^n(p) \\ &\quad -\rho\gamma''[r_1^s(p)-r_1^s(0)]-\gamma''[r_1^s(0)-\rho r_1^n(p)] \\ &= 2\gamma'[r_1^n(p)+r_1^s(0)-r_1^s(p)] \\ &\quad -\gamma''[r_1^s(0)-\rho r_1^n(p)-r_1^s(0)\rho+\rho r_1^s(p)]. \end{aligned} \tag{43}$$

Thus,

$$\begin{aligned} \partial^2\pi_b^+/\partial\rho^2 = &\ 2\gamma'\{pX-p[1-E][1+r_0][r_1^n(p)+r_1^s(0)-r_1^s(p)]\} \\ &-\gamma''\{[1-\rho]pX-p[1-E][1+r_0][[1-\rho]r_1^s(0)+\rho[r_1^s(p)-r_1^n(p)]]\}. \end{aligned} \tag{44}$$

Now because $\gamma'<0$, $r_1^n(p)<r_1^s(p)$ and from Eq. (10) it follows that $X>[1-E][1+r_0][1+r_1^s(0)]$, the first term in Eq. (44) above is negative. Moreover, $\rho\{1+r_1^s(p)-r_1^n(p)\} \leq 1$ (note that the left-hand side of this inequality is increasing in ρ, is equal to zero at $\rho=0$, and is equal to one at $\rho=1$because $r_1^s(p)=r_1^n(p)$ at $\rho=1$). Thus,

$$\rho[r_1^s(p)-r_1^n(p)] \leq 1-\rho \tag{45}$$

or

$$\begin{aligned} [1-\rho]r_1^s(0)+\rho\left[r_1^s(p)-r_1^n(p)\right] &\leq [1-\rho]+[1-\rho]r_1^s(0) \\ &= [1-\rho][1+r_1^s(0)]. \end{aligned} \tag{46}$$

Given Eq. (10), this implies that:

$$\begin{aligned} [1-\rho]pX &> p[1-E][1+r_0][1+r_1^s(0)] \\ &\geq p[1-E][1+r_0]\left[[1-\rho]r_1^s(0)+\rho[r_1^s(p)-r_1^n(p)]\right]. \end{aligned} \tag{47}$$

This means that the term multiplying γ'' in the second term on the right-hand side of Eq. (44) is strictly positive. Since $\gamma''>0$, it has been proved that $\partial^2\pi_b^+/\partial\rho^2<0$. □

Proof of Lemma 5. Totally differentiating the first-order condition yields

$$\frac{d\tilde{\rho}}{dX} = \frac{-[1-\beta_J]p\rho_n'(\rho)+[\partial\beta_J/\partial\rho]p\delta_n(\rho)}{SOC},$$

where SOC stands for "second-order-condition". Because $SOC<0$, $\partial\beta_j/\partial\rho>0$, and $\delta'_n(\rho)<0$, it follows that $d\tilde{\rho}/\,dX<0$. □

Proof of Theorem 1. Define

$$F(\rho^*,\tilde{\rho}) \equiv -[\partial\beta_J/\partial\rho]\pi_b^+(\tilde{\rho},\rho^*)+[1-\beta_J(\tilde{\rho})][\partial\pi_b^+/\partial\rho]=0 \tag{49}$$

as the bank's first-order condition, which must clearly be satisfied by any $\tilde{\rho}$. Moreover, given Lemma 4, it follows that $\tilde{\rho}$ is a unique optimum for the bank.

It is trivial to show that $\tilde{\rho}\neq 1$. This is because $\beta_J(\tilde{\rho})=1$ at $\tilde{\rho}=1$, making $U(\rho^*,\tilde{\rho})=0$, which means $\rho^*=1$ is not possible. Next, it is be shown that $\tilde{\rho}=\rho^*>0$. To see this, suppose counterfactually that $\tilde{\rho}=\rho^*=0$. Now note from Table 1 that the probability that investors draw $p_n=0$ and observe $\phi=n$ when the lead innovator bank has drawn $p_n=p$ and $\rho=\tilde{\rho}$ is $[1-\tilde{\rho}]\gamma(\tilde{\rho})$. Because $\lim_{\tilde{\rho}\to 0}\gamma(\tilde{\rho})=1$, it follows that $\lim_{\tilde{\rho}\to 0}[1-\tilde{\rho}]\gamma(\tilde{\rho})=1$. Thus, choosing $\tilde{\rho}=0$ means that the bank is denied second-period funding almost surely. Thus, $\tilde{\rho}=0$ cannot be an equilibrium.

This argument holds for any ρ^*, including $\rho^*=\tilde{\rho}$ and $\rho^*\neq\tilde{\rho}$. For $\tilde{\rho}\in(0,1)$, it follows that $U(\rho^*,\tilde{\rho})>0$ because $\beta_J(\tilde{\rho})\in(0,1)$ and $\pi_b^+(\rho^*,\tilde{\rho})>0$ for $\tilde{\rho}\in(0,1)$. Thus, $\tilde{\rho}>0$ for any $\tilde{\rho}\in[0,1]$.

Now, an equilibrium is a fixed point of ρ, i.e., $F(\rho^*,\rho^*)=0$, where $\tilde{\rho}=\rho^*$. The existence of an equilibrium is guaranteed by continuity and the arguments above. Moreover, the equilibrium is unique because $F(\rho^*,\rho^*)$ is monotonic in ρ^*. □

Proof of Theorem 2. Note first that the expected profit of the bank

$$U(\rho^*,\rho^*)=\theta[1-\beta_J]\pi_b^+(\rho^*,\rho^*), \tag{50}$$

is decreasing in $N\ \forall\ N\geq J+M$ (because a higher N leads to a stochastically higher N_n and hence a higher β_J) and is non-increasing in $N\ \forall\ N<J+M$. So start with a situation in which $N=J+M$. It is clear that $U>0$ at this N, because $\rho^*<1$. Given $\rho^*<1$, it follows that $\beta_J<1$, so $U>0$. If C is small enough, then $U>C$. Thus, for C small enough, N needs to increase further and $U=C$ at $N>J+M$. □

Proof of Theorem 3. Consider Eqs. (15) and (21) and the bank's first-order condition (25). The probability that the innovating bank's funding will be renewed a second period for any ρ, $\delta_n(\rho)$, is higher when $\gamma(\rho)$ is lower [see Eq. (15)]. Thus, $\partial\pi_b^+/\partial\rho$ is higher when $\gamma(\rho)$ is lower. Consequently, the first-order condition (25) yields the result that ρ^* is lower with γ_2 than with γ_1. The result that the probability of a crisis is strictly positive follows from the result that $\rho^*\in(0,1)$ (see Theorem 2) and the observation that a majority of banks, say $\hat{N}>(N/2)$, will be denied second-period funding is $\{[1-\rho^*]\gamma(\rho^*)\}^{N_n}+\{[1-\rho]\,[1-\overline{\gamma}]\}^{N-N_n}>0$, where N_n is the number of innovating banks and N is the total number of banks. □

Proof of Theorem 4. Note that

$$E(N_n^0|\rho)=\sum_{j=1}^{J}P_r(N_n=j)\left\{\rho N_n+[1-\rho]\sum_{i=1}^{N_n}i[1-\gamma(\rho)]^i[\gamma(\rho)]^{N_n-i}\right\} \tag{51}$$

It is clear that $\partial E(N_n^0|\rho)/\partial\rho>0$.

Now note that the number of banks entering the industry will be determined by the equilibrium entry condition for follower banks (since the expected profit on standard loans is zero):

$$\rho^*U(\rho^*,\rho^*)=C \tag{52}$$

where $U(\rho^*,\rho^*)$ is given by (50). This means that the lead innovator's expected profit, $U(\rho^*,\rho^*)$ is strictly positive in equilibrium. Differentiating the left-hand side of (52) yields

$$U(\rho^*,\rho^*)+\rho^*[\partial U(\rho^*,\rho)/\partial\rho] \tag{53}$$

Using the Envelope theorem enables (53) to be written as

$$U(\rho^*,\rho^*), \tag{54}$$

which is strictly positive. Thus, a small increase in ρ above a level ρ^* will increase the expected payoff of a follower bank above C and induce an increase in N, the number of entering banks. Moreover, since $U(\rho^*,\rho^*)>0$, this can be done without violating the participation (entry) constraint for the lead innovator. Thus, $\partial L/\partial\rho\big|_{\rho=\rho^*}>0$, so that $\rho_S^*>\rho^*$. □

Proof of Lemma 6. This proof follows immediately from the fact that unless investors observe $e_1=e$, they assess their expected repayment by the bank as zero and thus are unwilling to provide funding. □

Proof of Lemma 7. The result that the bank chooses $e_0=e$ follows immediately from the fact that investors refuse to provide funding at $t=0$ unless they observe $e_0=e$. The result that first-period investors do not provide any debt financing unless the bank puts up $E=B[1+\hat{k}_e]^{-1}$ in equity follows from the incentive compatibility constraint Eq. (30). The result that investors provide only single-period financing follows from the fact that $e_1=e$ cannot be contracted upon ex ante at $t=0$ and the bank therefore chooses $e_1=0$ if it is able to secure financing whose continuation at $t=1$ is not contingent upon $e_1=e$. Finally, the reason that shareholders are willing to provide financing that continues for two periods is that the presence of single-period debt assures them that the incentive compatibility constraint for the bank to choose $e_1=e$ will be satisfied. In the absence of single-period debt, shareholders also anticipate $e_1=0$ and refuse to fund the bank. □

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