Latin American Journal of Central Banking 1 (2020) 100008

Contents lists available at ScienceDirect

Latin American Journal of Central Banking

journal homepage: www.elsevier.com/locate/latcb

Interconnectedness, systemic crises, and recessions ☆

Marco A. Espinosa-Vega [a,*], Steven Russell [b]

[a] Financial Institutions Statistics Department, International Monetary Fund, United States
[b] Department of Economics, IUPUI, United States

ARTICLE INFO

JEL classification:
G11
G12
G20
G33

Keywords:
Financial crisis
Systemic risk
Interconnectedness
Recession

ABSTRACT

In this paper, we construct a simple model designed to capture four widely held views about financial crises: [1] Interconnectedness among financial institutions (banks) can play a major role in precipitating systemic financial crises. [2] It does so by introducing loan-portfolio opacity, reducing the quality of information about portfolio risk. [3] Financial crises, particularly systemic ones, often are followed by serious recessions. [4] A loss of confidence in the financial system is partly responsible for the length and severity of these recessions. In the model, banks assess loan risk, originate and liquidate loans, and acquire loans originated by other banks. Interconnectedness of this sort can obscure information, resulting in banks making inefficient decisions about liquidating loans and choosing loan originators (who assess risk). Inefficient liquidation can deepen recessions and lead to systemic financial crises; less effective risk assessment can increase the probability of lengthy, severe recessions. The government may wish to increase the transparency of bank portfolios by limiting interconnectedness. The optimal degree of regulation may depend on depositors' degree of risk aversion and may not eliminate financial crises.

1. Introduction

An extremely large number of financial institutions were affected by the unusually severe financial crisis of 2008-2009. The crisis was followed by a deep, prolonged recession (the "Great Recession"), and by a much longer period of economic malaise. By some accounts, the crisis grew out of problems with financial institutions' asset portfolios, which were interconnected to a high and unprecedented degree. These circumstances created the impression that interconnectedness among financial institutions can make the economy more vulnerable to systemic financial crises, and they reinforced the long-held belief that recessions following financial crises tend to be exceptionally severe.[1] They also produced proposals for government regulation to limit interconnectedness.[2]

The recent financial crisis is also widely believed to have been caused, at least in part, by a lack of complete and accurate information about the state of the financial institutions' asset portfolios. From this perspective, the recession that followed the crisis

☆ We thank two anonymous referees for valuable suggestions, and we thank Jean-Charles Rochet and the participants in our session at the Midwest Economic Theory meetings in the spring of 2014 for their helpful comments. Russell conducted much of his part of this research as a visiting scholar at the Institute for Capacity Development of the International Monetary Fund. The views expressed herein are those of the authors and should not be attributed to the IMF, its Executive Board, or its management.

* Corresponding author.
E-mail address: mespinosa@imf.org (M.A. Espinosa-Vega).

[1] For recent evidence on this question, see Reinhart and Rogoff (2009) and Kannan et al. (2009). Jordá et al. (2014), use a new international data set and advanced econometric techniques to find that, over five-year recession/recovery periods, the cumulative output loss from recessions associated with financial crises, relative to other recessions, averages 20 percent of GDP.

[2] See, for example, the proposals discussed in Gambacorta and van Rixtel (2013).

https://doi.org/10.1016/j.latcb.2020.100008
Received 16 February 2020; Received in revised form 24 June 2020; Accepted 10 August 2020

occurred, at least in part, because credit became difficult for risky borrowers to obtain, as financial institutions and their funders lost confidence in the institutions' ability to assess credit risk effectively.[3]

The Financial Crisis Inquiry Report, prepared by the National Commission on the Causes of the Financial and Economic Crisis in the United States, summarizes many of these views clearly and succinctly (2011, page 10):

> The crisis reached seismic proportions in September 2008 with the failure of Lehman Brothers and the impending collapse of the American International Group (AIG). Panic fanned by a lack of transparency of the balance sheets of major financial institutions, coupled with a tangle of interconnections among institutions perceived to be "too big to fail," caused the credit markets to seize up. Trading ground to a halt. The stock market plummeted. The economy plunged into a deep recession.

In this paper, we lay out a model which delivers predictions that seem consistent with these views. In our model, "interconnectedness" means assets-side diversification of a particular type: financial institutions, which we call banks, devoting part of their loan portfolios to loans originated by other banks. We recognize that this is only one of many ways in which financial institutions may be connected to each other, and that this sort of interconnectedness is not the only form of interconnectedness that may have contributed to the financial crisis. Banks also are connected to each other on the liabilities side, for example, and the unexpected needs for liquidity exacerbated by this type of interconnectedness may have played an important role in starting or propagating the financial crisis.

In this paper, we're focusing on assets-side interconnectedness of a particular variety. This choice of focus was inspired largely by the apparent role of uncertainty about the value of mortgage-backed securities in producing and driving the crisis. However, we wouldn't argue that other forms of interconnectedness may not have been important. Somewhat similarly, although we are following much of the simple-model literature on financial intermediation and/or financial policy by referring to our financial institutions as "banks," we recognize that they do not engage in many activities conducted by most actual banks, and that they do engage in some activities conducted by many non-bank financial institutions. Thus, to the extent that this is a paper about financial regulatory policy, it has implications for policy toward many types of financial institutions, not just banks. Finally, and again in line with much of the related literature, we are not distinguishing between different types of financial assets: loans, securities, equities, etc. There is only one type of bank asset here; it is very simple, and it shares features with all those real-world assets.

Asset-side interconnectedness comes in different varieties: banks purchasing loans from other banks, or purchasing loan-backed securities, or banks lending to each other. The latter sort of interconnectedness is often studied in applied literature that tries to assess the magnitude of systemic risk and the practical effectiveness of different strategies to reduce the risk via bank regulation, such as Espinosa-Vega and Sole (2011) and Batiz-Zuk et al. (2016). In these numerical models, interbank lending can lead to bank failures via "domino effects" triggered by return or funding shocks. Roukny et al. (2018) provide a more theoretical contribution, emphasizing the possibility of multiple equilibria when there is extensive interconnection in the interbank lending market.

Formally, our model studies interconnectedness produced by loan purchases. Under our simple loan- and deposit-return assumptions, the two sorts of interconnectedness are equivalent. Although that is not true in practice (or in Roukny et al. (2018), for example) because large loans to banks may have different payoff distributions from multiple smaller loans purchased from banks, we think our results have something to say about the potential dangers of interbank-lending interconnectedness and the potential benefits from restricting it.

Examples of other papers in which "interconnectedness" has a meaning similar to ours include Bimpikis and Tabaz-Salehi (2013), Ibragimov et al. (2011), and Wagner (2010, 2011). In all these papers, including ours, interconnectedness produces relatively adverse outcomes for the asset portfolios held by banks at the time of a crisis. These adverse outcomes often arise because interconnectedness increases the likelihood that banks will fail simultaneously. In Wagner's papers, simultaneous failures produce bad outcomes by necessitating "fire sales" of liquidated assets. According to Bimpikis and Tabaz-Salehi, the joint failures simply produce very low returns on deposit portfolios, which are loathed by risk-averse depositors.

Unlike many models in this literature, such as Wagner's models, our model gives diversification its traditional advantage from portfolio theory. We assume, along with Bimpikis and Tabaz-Salehi, that depositors are risk averse, and that diversification tends to increase their welfare (expected utility) by reducing the variance of their returns across portfolios and states of the world.[4]

In our model, interconnectedness has three potential disadvantages that may outweigh this advantage. The first involves financial contagion: the idea that liquidity and/or solvency problems that start at one or a few institutions ultimately spread to other institutions to which they are connected. In analyses in the financial contagion literature, low returns on institution-originated loans hurt the returns on portfolios of connected institutions, directly or indirectly, increasing the likelihood that these institutions will fail. Allen and Gale (2000) make a classic contribution to the literature on this subject. In their model, low returns are caused by liquidity shocks that require asset liquidation, and the interconnectedness between banks is on the liabilities side.

Our two-bank model produces contagion, of roughly this sort, that results from assets-side interconnectedness. When our banks' loan portfolios are interconnected, information about portfolio returns is not a reliable guide to the performance of loans originating from a particular bank. As a result, both banks can fail (liquidate their loan portfolios) even if only one of them made bad loans. In this way, a financial crisis that could have been localized, resulting in the failure of only one bank, can create a systemic crisis.

A related disadvantage involves negative spillovers to the real sector of the economy. When banks liquidate their loan portfolios, they inevitably liquidate some loans that would have performed well (a type of fire sale); when they do not liquidate their portfolios,

[3] For safe borrowers, such as the U.S. Treasury and consumers or firms with sterling credit, interest rates fell substantially.

[4] Ibragimov et al. assume that intermediaries must pay a premium for each unit of risk in their portfolios, but they do not endogenize this premium.

they sometimes fail to liquidate loans that would have performed badly. This problem increases the severity of crisis-induced recessions even when the crises are not systemic. When banks are fully interconnected, this happens because their portfolio returns are similar to each other (here, identical), even though the performance of the loans they originated may be quite different. When they are partly interconnected, it happens because liquidation destroys potentially useful information linking originators to low portfolio returns.

The third and most important disadvantage of interconnectedness in our model stems from one of our basic assumptions about the economic role of banks. As Bernanke (2007) has emphasized, banks are useful partly because they have acquired informational capital: information about potential borrowers that allows them to assess credit risk relatively accurately. [5] In our model, banks, or more specifically their managers, may not be equally skilled at risk assessment. A bank makes bad loans because its managers have turned out to be unskilled at assessing credit risk (incompetent) and need to be replaced. However, when each bank's portfolio includes loans that managers of the other bank initiated, the identity of the bank whose loans produced a bad portfolio outcome may not be apparent. The result can be a different kind of contagion: Mistakes committed by incompetent mangers may "infect" institutions with managers who are relatively skilled at risk assessment, creating doubts about their competence. As a result, the managers of both banks may be replaced. However, new managers have less informational capital (are less skilled at assessing credit risk) than experienced ones. Thus, a situation in which part of the financial system suffers a temporary loss of informational capital can be transformed, via interconnectedness, into a situation in which the entire system suffers this loss, because one institution initiates bad loans but both institutions fail and both sets of loan officers are replaced. The result can be a substantial increase in the likelihood of low return outcomes on portfolios of loans initiated in the near future.

We think our incompetence-at-risk-assessment story captures the view about the cause of the post-crisis recession that we summarized in the second paragraph of this introduction. According to this view, the huge losses many financial institutions suffered during the crisis shook lenders' confidence in the financial system's ability to assess credit risk effectively. As a result, institutions had more difficulty raising funds to finance risky loans; interest rates on these loans rose; and investment, employment, and output declined. We describe a simple mechanism by which interconnectedness among financial institutions can allow bad outcomes on loans originated by some institutions to cause depositors to lose confidence, rationally, in the effectiveness of future risk assessment across the financial system. This mechanism can cause current interconnectedness to reduce the efficiency of future risk assessment, increasing the likelihood that recessions will be long and severe.

In reality, a bank's upper management makes many decisions that do not involve credit risk assessment, and it may have a fairly limited direct role in formulating credit risk assessment practices. A bank's success at credit risk assessment may depend primarily on the abilities of its loan origination officers, and there may be considerable informational distance between them and its upper management. In our analysis, we characterize bank managers as competent or incompetent only along a single dimension: risk assessment. In their other activities, they are invariably competent. However, the possibility that there may be some informational distance between a bank's managers and its risk assessors/loan originators may help justify a potentially controversial assumption we make about the circumstances under which loan portfolios are liquidated.

The way we model the decisions banks make about their managers causes the decisions made by current depositors, and by current managers on their behalf, to influence the characteristics of the return distribution facing future depositors. This situation produces a business cycle, of sorts: In the model's second period, expected loan returns are lower, and recessions are more likely, than in its first period. Interconnectedness tends to increase this cycle's amplitude.

The link between the decisions of current depositors and the returns received by future depositors also produces an intertemporal externality, because our assumptions imply that current depositors act to maximize their expected utility from current deposit returns.[6] However, the government cares about both current and future depositors. This situation creates a potential rationale for government intervention to restrict interconnectedness. The regulatory policy we study is simple: The government may limit or even prohibit interconnectedness. Regulation of this sort is likely to reduce the attractiveness of the current deposit return distributions, by increasing their variability. However, it can increase future depositors' expected returns substantially, while also providing some benefits in terms of current expected returns. It does this by making the banking system more transparent. Depositors can more easily use the information available to them to determine the characteristics of their banks' asset portfolios, and they can use this information to improve the efficiency of their liquidation and manager replacement decisions.

For the moment, our description of the model's predictions is based on a two-version numerical example. Although we hope to generalize the predictions at some point, the model is complicated enough that working with a numerical example seems like a reasonable first step.

In the next section, we outline the analysis presented in this paper. In the third section, we lay out the model's main features. The fourth section completes the model's description and explains how we define and describe equilibria, which requires us to examine the sometimes-intricate interactions between the model's main features. The fifth section describes the two versions of our baseline numerical example and examines the characteristics of the equilibrium it supports. The sixth section presents some concluding remarks.

[5] See Greenwood and Jovanovic (1990), in which banks contribute to the growth process by allowing investors to choose better projects and get higher rates of return, and Boissay et al. (2016), who use the assumption that banks are heterogeneous with respect to intermediation skills to generate an interbank loan market.

[6] In the model presented here, they do this because there are two cohorts of depositors, each of which lives for only one out of the model's two periods. In Appendix A, we argue this assumption is not essential for our results: We can generate the same behavior when both the depositors and the government have the same (two-period) decision horizons.

2. Outline of our analysis

We construct a two-period model in which there are two *ex ante* identical banks, each operating in each period. The banks use funds provided by one-period-lived depositors to make loans that finance simple, one-period investment projects: one project per deposit. Each period, each bank has a management team (its managers) that decides which projects to finance. The gross loan returns are the entire gross returns on the projects; the banks pass along all these returns to their depositors. The returns on loans the bank's managers originated are either relatively high (good) or relatively low (bad). All the loans originated by a particular bank deliver the same return, but the loans extended by the other bank may deliver a different return.

Loan return outcomes depend primarily on the risk-assessment ability (competence type) of the bank managers who originate them. These managers may be competent or incompetent. Competent managers make good loans with high probability; incompetent managers always make bad loans. All managers are initially competent, but some may "lose their touch": If competent managers make bad loans in a period, then they are incompetent in the following period. In addition, experience enhances competence: If competent managers make good loans in a period, the probability they will make good loans in the following period is higher than the corresponding probability for competent managers who were not employed by banks in the previous period (new managers).

In period 1, both banks' managers are competent and experienced, by assumption. If they make good loans in period 1, they are competent and experienced in period 2. If they make bad loans in period 1, they are incompetent for period 2. At the beginning of the second period, each bank's depositors have the option to replace the bank's original managers with new managers who are competent but inexperienced.

A bank's managers have the option to exchange loans they originated, one-for-one, for loans the managers of the other bank originated, provided both parties agree. Each bank receives the total gross return on any loan it acquires (purchases) in this way. When loan purchasing occurs, we say the two banks are "interconnected." Interconnection is attractive to banks because it spreads risk, and their depositors are risk averse.[7]

Each bank's managers can liquidate, prior to completion, projects financed by loans the bank owns. "In the middle" of each period, each bank's depositors receive a signal indicating whether the average return on the bank's loan *portfolio* will be higher or lower than the return from liquidating a project. They have the right to respond to the signal by withdrawing their deposits, thus receiving payments equal to the project-liquidation return. The bank's managers finance these withdrawals by liquidating projects/loans.

In our model, banks provide two principal services for depositors. The first and most important is credit risk assessment. The second service, which is provided only when the banks are interconnected, is risk spreading, allowing depositors to hold shares of diversified, lower-return-variance loan portfolios. Our banks do not issue liabilities with shorter terms than their assets, and they do not reallocate portfolio risk across holders of different liability types. In addition, although depositors may withdraw their deposits at an early stage, they do not do so to satisfy needs for liquidity, as in Diamond and Dybvig (1983) and many subsequent analyses. Instead, they do it to force banks to liquidate bad loans, somewhat as in Calomiris and Kahn (1991).

If the two banks are not interconnected in either period, events and decisions in the model play out in a relatively simple way because there is complete clarity about loan returns: Loan portfolio returns, which are public information, and loan returns by the originator are the same thing. In period 1, a bank liquidates its loan portfolio if it gets the unfavorable interim signal, but does not do so otherwise. The bank can infer with certainty, from the identity of the signal, that all the loans in its portfolio are good or are bad, and thus should or should not be liquidated. In period 2, the depositors of a bank that liquidated its portfolio in period 1 replace its managers; the depositors can infer with certainty, from the observed portfolio return, that these managers made bad loans and are incompetent.

As indicated, interconnection is attractive to banks because it spreads loan-return risk. However, it introduces some opacity (incomplete information), because loans owned and loans originated are no longer the same thing, and a bank's portfolio returns are no longer the same thing as the returns on the loans its managers originated. In particular, [1] when the loans a bank owns are liquidated, some loans may not be bad (and vice versa), and [2] when a bank's depositors observe the bank's loan portfolio returns from the preceding period, they may not be able to determine whether the bank's managers from that period (its presumptive current managers) are competent or incompetent. Consequently, a bank's depositors may make *ex post* errors in deposit withdrawal (and resulting loan liquidation) decisions and/or in manager replacement decisions.

Our model produces circumstances in which a bank's depositors will rationally replace managers who were competent and should not have been replaced, or will not replace managers who were incompetent and should have been replaced. Both types of mistakes reduce the expected return on the bank's loan portfolio in period 2. In addition, in either period, some good loans may be liquidated or some bad loans may not be liquidated. Both types of mistakes reduce the expected returns on bank loan portfolios in the relevant periods.

We think of the periods in which the managers of one of the two banks make bad loans (turn out to have been incompetent) as recession periods, and we think of the periods in which at least one of the two banks liquidates its loan portfolio as periods of financial crisis. If both banks liquidate their portfolios, we think of the financial crisis as severe. Furthermore, if a recession or a financial crisis occurs in both periods, we think of the recession or crisis as lengthy.

By assumption, if both banks' managers are competent then they cannot both lose their competence (originate bad loans) in the same period. It follows that if the banks are not interconnected, severe financial crises cannot occur, and recessions and financial

[7] The interconnection produced by the banks that are lending to each other would be equivalent, provided the loan repayments were equal to the returns on the projects that the loans financed.

crises always coincide. However, when the banks are interconnected a severe financial crisis can occur, because both banks may liquidate their loan portfolios even though the managers of only one bank were incompetent. Thus, we think of a severe financial crisis as a systemic phenomenon: one that can occur only when the banks are part of an integrated system. Since the accompanying recession features lower total loan returns than any other recession, we think of it as severe. So we say that severe recessions are caused by severe financial crises and are systemic in origin.

Our model produces a simple form of a business cycle. Even when the banks are not interconnected, a recession/crisis in period 1 increases the probability of a recession/crisis in period 2, because in period 2, the managers of one of the two banks are inexperienced. When the banks are interconnected, the probability of a lengthy (two-period) recession increases, because after some financial crises, both sets of bank managers are inexperienced. Financial crises that are both lengthy and severe also become possible.

We study three bank-interconnectedness (loan portfolio diversification) regimes: one in which the two portfolios are completely (maximally) diversified; one in which they are partly diversified; and one in which they are not diversified at all, so that the two banks are not connected to each other. In our baseline examples, if there is no government regulation then the depositors of period-1 banks choose complete diversification for any of the degrees of depositor risk aversion we study. The lower expected loan returns caused by the possibility of liquidation mistakes are more than offset by the reduced return variance caused by risk-spreading. The period-1 depositors do not internalize their tendency to decide about interconnectedness to reduce the prospects for their successors. However, the government cares about the average expected utility of both groups of depositors. As a result, when the depositors are weakly risk averse, so that the benefits from loan portfolio diversification are relatively small, the government prohibits interconnectedness in period 1, eliminating the possibility of severe financial crises and ensuring the smallest possible probability of a recession in period 2. When the depositors are more strongly risk averse the government restricts but does not prohibit interconnectedness, reducing but not eliminating the incidence of severe crises.

3. Model specification

3.1. Basic setup: Banks, depositors, loans

There are two periods, with two *ex ante* identical banks that operate in both periods. In each period, each bank has an equal-measure continuum of one-period-lived depositors. There are two goods: an input and an output. Each depositor has an input good endowment sufficient to fund one risky project. These projects produce the output good, which depositors consume. Each project starts at the beginning of a period and is completed at the end of the same period.

Banks use funds (goods endowments) from depositors to originate loans to finance projects their managers choose. The loan returns are identical to the project returns; henceforth, we usually refer to the loans and not the projects. The depositors of a bank also are its owners, and the returns on the bank's loan portfolio are divided equally among them. They are indifferent to the point in a period when they receive these returns.

A bank's loan portfolio may include loans originated by the other bank's managers. This happens if both banks' managers agree to exchange loans originated by their bank for loans originated by the other bank, loan for loan (and project for project).

Projects are either good, in which case they deliver relatively high returns, or bad, in which case they deliver relatively low returns. There are measure-zero good projects among the continuum of available projects, so choosing projects randomly never yields good projects. For this reason, depositors, who are assumed to have a no risk-assessment capacity, cannot choose good projects themselves. The model includes two-period-lived agents (or teams of agents) who we call managers. They come in two types: those with a relatively high positive probability of being able to identify good projects—the competent type—and those who can do no better than choosing projects randomly—the incompetent type. Thus, competent managers sometimes make bad loans, but incompetent managers always do so.

Bank managers choose projects to fund, and they make loan portfolio diversification and loan liquidation decisions. They make these decisions in the interests of the depositors of the banks that employ them, with a single exception described below. We do not model the number, compensation, or consumption of managers.

All managers are competent in the first period in which they manage a bank, but can lose their competence after that period. Managers who are competent in a period and make good loans remain competent in the following period. Managers who are competent in a period but make bad loans have lost their competence and are incompetent in the following period. In addition, the probability that competent managers make good loans depends on their degree of experience. Competent managers who made good loans in the previous period—experienced managers—have a relatively high probability of making good loans this period. Competent managers who were not employed by a bank in the previous period—inexperienced managers—have a lower probability of making good loans in the current period.

If both banks' managers are competent then the returns on their loans are positively correlated. The probability that both banks' managers make good loans is higher than the product of the two marginal probabilities, and the probability that both banks' managers make bad loans is zero.

At the beginning of each period, each bank has incumbent managers. Its depositors must decide whether to retain or replace them. For period 1, this decision is easy: By assumption, both banks' incumbent managers are competent and experienced.[8] In period

[8] Although there is no period 0, we think of the situation at the beginning of period 1 as being “as if” both banks' incumbent managers had managed their respective banks in period 0 and made good loans.

2, when a bank's incumbent managers are its managers from period 1, this decision may be harder. We also assume that if a bank replaces its managers, the new managers are inexperienced.[9]

The depositors of either bank are not able to observe, directly, whether a bank's incumbent managers are competent, even after deposit returns from the preceding period have been paid and observed. There can be circumstances under which a bank's depositors cannot determine the competence of its incumbent managers because whether the loans they made during the previous period were good or bad is not clear.

A project started at the beginning of a period can be liquidated before its returns are realized (or observed). Project liquidation produces a fixed (nonstochastic) return that is invariant to the type of manager that funded the project. A bank's managers can liquidate projects funded by loans the bank owns. Depositors have the right to withdraw their deposits before the end of the period, receiving immediate payments equal to the liquidation value of a loan. Since they do not care about the timing of their deposit returns, they withdraw their deposits only to increase their expected returns.

At some point "in the middle" of each period, each bank's depositors and managers receive a 1-0 signal indicating whether the average return on the bank's loan *portfolio* will be higher or lower than the liquidation return (they do not observe the other bank's signal.) The signal is perfectly accurate but provides no additional information. A bank's depositors may respond to the signal by withdrawing their deposits; the bank's managers liquidate loans to finance these withdrawals.

When a bank's depositors make decisions, or when a bank's current managers make decisions on their behalf, they do so to maximize the depositors' expected utility from consumption, calculated using the constant-relative-risk-aversion utility function $u(c) = (c^{1-\gamma} - 1)/(1-\gamma)$, for $\gamma > 0$. We consider three alternative values for γ: $\gamma = 1$ [in which case $u(c) = \ln c$], $\gamma = 2$, and $\gamma = 4$. We think of $\gamma = 1$ as the case in which the depositors are not very (are weakly) risk averse, $\gamma = 2$ as the case in which they are moderately risk averse, and $\gamma = 4$ as the case in which they are strongly risk averse. We do this because $\gamma = 1$ is at the low end of the range of empirical estimates of the relative risk aversion coefficient, while $\gamma = 4$ is widely used to represent the behavior of agents who are quite strongly risk averse.

3.2. Return distributions on loans

3.2.1. Base returns and random shocks to them

Each period, all the loans a bank's managers originate yield the same total return. This total return is the sum of two random variables: a base return variable, which is associated with the managers' competence, and a relatively small random shock, the distribution of which depends on the identity of the base return outcome. The base return variable has two outcomes, good or bad: g or b units of the output good per project, respectively, where $0 \leq b < g$. In our baseline numerical example—the only example examined in this paper—we choose $g = 1$ and $b = \frac{1}{2}$. Two random shocks are associated with each base return outcome: $\pm\,\varepsilon^g$ for the good outcome, equally likely, and $\pm\,\varepsilon^b$ for the bad outcome. These shocks are independent across loan originators and periods. We assume $\varepsilon^g > \varepsilon^b \geq 0$, $\varepsilon^g < g$, and $\varepsilon^b < b$. The examples we construct always come in two versions: a version in which $\varepsilon^b = 0$ (Version 1) and an otherwise-identical version in which $\varepsilon^b > 0$ (Version 2). In our baseline example, $\varepsilon^g = \frac{1}{3}$; in Version 2 of that example, $\varepsilon^b = \frac{1}{12}$. The second versions of the examples allow us to generate financial crises that are not systemic, in the sense described in the introduction and in Section 4.7.

To summarize the link between loan return components and the language we use to describe them: the base loan return outcomes are g or b, the random shocks to the base return outcomes are $\pm\,\varepsilon^g$ and $\pm\,\varepsilon^b$, respectively, and the total loan return outcomes (by originator) are $i \pm \varepsilon^i$, $i = b, g$. If the two banks are interconnected, then the average loan portfolio return outcomes (also deposit return outcomes), which are described in the next subsection, are weighted sums of loan returns.

We also assume:

Assumption 1a. $b + \varepsilon^b < g - \varepsilon^g$.

This assumption ensures that the worst possible total return from a good loan is better than the best possible total return from a bad loan. It follows that if the total loan returns are observable or inferable, the managers who made good (or bad) loans can be inferred to be competent (or incompetent).

The base return distributions for loans the two banks' managers originated are independent across periods, but not within periods.

3.2.2. Base loan return determinants: manager competence

Marginal returns: If a bank's current managers also managed the bank in the previous period and originated good loans (loans that yielded the good base return), they are competent and *experienced* this period. In this case, their probability of making good loans this period is denoted p^e. We assume $1/2 < p^e < 1$; in our baseline example, $p^e = 3/4$. If a bank's current managers originated bad loans in the previous period, they are *incompetent* this period, and their probability of making good loans is zero. Finally, if a bank's current managers did not originate loans in the previous period, they are competent but *inexperienced* this period, and their probability of making good loans is denoted p^i. We assume $0 < p^i < p^e$; in our baseline example, $p^i = 1/2$.

Joint returns: In any period, the joint distribution of the base returns on the loans originated by the managers of the two banks—which must, of course, be consistent with the marginal distributions—depends on the characteristics of both sets of man-

[9] Since there are only two banks, a bank could hire experienced new managers, in period 2, only by hiring them away from the other bank. We rule this out by assuming that experienced managers prefer to stay with the bank they worked for in the preceding period, if they have that option.

Table 1
Marginal and joint base loan return distributions.

Baseline example
Marginal outcomes in regular type
Joint outcomes in italics

Both banks' managers are experienced *ee*

		Bank B	
		Good outcome g $p^e = 3/4$	Bad outcome b 1/4
Bank A	Good outcome g $p^e = 3/4$	*Pure outcome* $p^{ee} = 1/2$	*Mixed favoring A* 1/4
	Bad outcome b 1/4	*Mixed favoring B* 1/4	0

Bank A's managers are experienced; Bank B's are inexperienced *ei*

		Bank B	
		Good outcome g $p^i = 1/2$	Bad outcome b 1/2
Bank A	Good outcome g $p^e = 3/4$	*Pure outcome* $p^{ei} = 1/4$	*Mixed favoring A* 1/2
	Bad outcome b 1/4	*Mixed favoring B* 1/4	0

Here, $p^{me} = 2/3$, so that a mixed outcome favoring Bank A is twice as likely as a mixed outcome favoring Bank B.

Both banks' managers are inexperienced *ii*

		Bank B	
		Good outcome g $p^i = 1/2$	Bad outcome b 1/2
Bank A	Good outcome g $p^i = 1/2$	*Pure outcome* $p^{ii} = 0$	*Mixed favoring A* 1/2
	Bad outcome b 1/2	*Mixed favoring B* 1/2	0

agers. As we have indicated, *one of our key assumptions about this distribution is that if the managers of both banks are competent then the probability they both originate bad loans is zero*.

Pure returns: If the loans originated by both sets of managers turn out to be good, we call the joint base return outcome "pure." When both sets of bank managers are experienced, the probability of a pure return outcome is denoted p^{ee}. When both sets of managers are inexperienced, it is denoted p^{ii}.

Mixed returns: If the loans originated by one bank's managers turn out to be good, while those originated by the managers of the other bank turn out to be bad, we call the joint base return outcome "mixed" and we say it "favors" the first bank. We assume that when both sets of managers have the same competence/experience characteristics the probabilities of mixed joint base return outcomes favoring each bank are equal. Thus, we must have $p^{ee} + (1 - p^{ee})/2 = p^e \Leftrightarrow p^{ee} = 2p^e - 1$ and $p^{ii} + (1 - p^{ii})/2 = p^i \Leftrightarrow p^{ii} = 2p^i - 1$. It follows that we must require $p^i \geq 1/2$ (a condition just satisfied in our baseline example) and that $0 \leq p^{ii} < p^{ee}$. In our baseline example, $p^{ee} = 1/2$ and $p^{ii} = 0$.

If one bank's managers are experienced and the other bank's managers are inexperienced then the probability of a pure joint base return outcome is denoted p^{ei}. We must have $p^e = p^{ei} + p^{me}(1 - p^{ei})$ and $p^i = p^{ei} + (1 - p^{me})(1 - p^{ei})$, where p^{me} is the probability that the joint base return outcome favors the experienced managers, conditional on that outcome being mixed. It follows that $p^{ei} = p^e + p^i - 1$ and $p^{me} = (1 - p^i)/(1 - p^{ei})$ that $p^{ii} < p^{ei} < p^{ee}$. Thus, the probability of a pure joint base return outcome increases with the experience level of the managers. In our baseline example, $p^{ei} = 1/4$, and $p^{me} = 2/3$.

If the managers of a bank are incompetent then the base return variable for loans they originate has a degenerate distribution: b with probability 1.

The base loan return distribution assumptions for our baseline example are summarized in Table 1 above. The table is confined to cases in which the managers of both banks are competent.

3.3. Bank interconnectedness (loan portfolio diversification)

The managers of the two banks can diversify their banks' loan portfolios by exchanging loans they have originated for loans originated by the managers of the other bank. If this happens, we characterize the two banks as interconnected, and we think of them as parts of a banking system. We study three alternative regimes for portfolio diversification (interconnectedness): no diversification (ND), in which case each bank's portfolio consists entirely of loans its managers originated; partial diversification (PD), in which case each bank's portfolio consists partly of loans it originated and partly of loans managers of the other bank originated, with the former predominating; and complete diversification (CD), in which case each bank's portfolio is equally divided between loans its managers originated and those originated by the managers of the other bank.

We will let d, for either bank, represent the ratio of loans in its portfolio originated by the managers of the other bank to those originated by its own managers. We study the cases $d = 0$ (ND), $d = 1$ (CD), and some particular value d satisfying $0 < d < 1$ (PD). It is often more convenient to work with the parameter $\theta = d/(1+d)$, which is the fraction of a bank's portfolio that consists of loans originated by the managers of the other bank, so that $\theta \in (0, \frac{1}{2})$ under PD. Henceforth, an unsubscripted θ refers to the value of this parameter under PD. In our baseline example, we choose $d = \frac{1}{2}$ for PD, which is $\theta = \frac{1}{3}$.

We confine ourselves to these three alternatives because we want to generate information problems in a simple model where we can work with discrete probability distributions and avoid complex problems of statistical inference.

If we let θ_h, $h = 1,2,3$ represent the θ-values for ND, PD, and CD, respectively, so that $\theta_1 = 0$, $\theta_3 = \frac{1}{2}$, and $\theta_1 < \theta_2 < \theta_3$, and if we let $\varepsilon_i^v = (-1)^{i-1}\varepsilon^v$, $v = g, b$, $i = 1,2$, we can characterize the set of potential joint *portfolio* return outcome pairs for the two banks $\{A, B\}$ for each diversification regime s as follows:

$$\left\{\begin{array}{l} \left\{\left(1-\theta_h\right)\left(g+\varepsilon_i^g\right)+\theta_h\left(g+\varepsilon_j^g\right),\ \left(1-\theta_h\right)\left(g+\varepsilon_j^g\right)+\theta_h\left(g+\varepsilon_i^g\right)\right\} \\ \cup\left\{\left(1-\theta_h\right)\left(g+\varepsilon_i^g\right)+\theta_h\left(b+\varepsilon_j^b\right),\ \left(1-\theta_h\right)\left(b+\varepsilon_j^b\right)+\theta_h\left(g+\varepsilon_i^g\right)\right\} \\ \cup\left\{\left(1-\theta_h\right)\left(b+\varepsilon_j^b\right)+\theta_h\left(g+\varepsilon_i^g\right),\ \left(1-\theta_h\right)\left(g+\varepsilon_j^g\right)+\theta_h\left(b+\varepsilon_i^b\right)\right\} \end{array}\right\},\ h=1,2,3,\ i=1,2,\ j=1,2.$$

Thus, in the first versions of our examples, there are eight joint total return outcomes—four associated with pure base loan return outcomes, and four associated with mixed outcomes. In the second versions, there are twelve total loan return outcomes, four associated with pure base loan return outcomes and eight associated with mixed outcomes. Collectively, the four pure total loan return outcomes comprise the first element of a three-element set that includes all the joint total return outcomes. The other elements of that set are the mixed joint total return outcomes favoring Bank A and Bank B, respectively. In our Version 1 examples, there are two mixed joint total loan return outcomes favoring each bank; in the Version 2 examples, there are four.

As we shall now see, the set of realized total loan return outcomes differs from the set of potential total return outcomes in that, if any of the potential portfolio total return outcomes has a value less than the liquidation value q then its realized value becomes q in equilibrium.

3.4. Liquidation of loans

As we have indicated, banks can liquidate any desired fraction of projects funded by loans they own, regardless of the originator. Liquidating a project yields q units of the output good, which becomes the repayment on the loan that financed the project.

Since liquidation must occur quickly, *we assume that a bank cannot control which of the projects in its portfolio are liquidated* (we will say more about this assumption below). Thus, the fraction of projects liquidated by a bank that were financed by loans originated by the managers of that bank is equal to $1-\theta$, the fraction of those loans in the bank's portfolio.

As we have also indicated, a bank's managers liquidate projects in response to withdrawal requests from the bank's depositors. Each period, each depositor has a right to withdraw their deposit "in the middle" of the period, obtaining a payment of q but forfeiting any share of the end-of-period deposit return. Also in the middle of each period, the depositors and managers of each bank receive a private signal about the total return on the bank's loan portfolio. The signal, which is perfectly accurate, indicates whether the average loan repayment will exceed q (a favorable signal) or fall short of q (an unfavorable signal). The signal does not provide any information about the prospective returns on different components of the bank's portfolio, if there are any: in particular, it provides no information about prospective differences in the returns on the loans originated by the managers of the two banks. The bank's depositors may respond to the signal by withdrawing their deposits.

We make two return assumptions that help determine the circumstances under which liquidation occurs. The first elaborates Assumption 1a:

Assumption 1b. $b+\varepsilon^b < q < g-\varepsilon^g$.

Under this this assumption, if we abstract from information problems then it is always efficient to liquidate bad loans, and it is never efficient to liquidate good ones. In addition, the assumption ensures that, if the joint return outcome is pure then neither bank gets the unfavorable signal, regardless of the diversification regime. In addition, if the banks' portfolios are not diversified then at most one bank gets the unfavorable signal.

Assumption 2. $(1-\theta)(g-\varepsilon^g)+\theta b < q < \theta(g+\varepsilon^g)+(1-\theta)(b-\varepsilon^b)$.

Assumption 2 implies that if there is any diversification (PD or CD), it is possible for both banks to get the unfavorable signal (the left-hand side inequality), and that if the joint return outcome is mixed and the good loans get the high shock, it is not possible for either bank to get the unfavorable signal (the right-hand side inequality).[10] When combined with Assumption 1, it also implies $(1-\theta)b+\theta(g-\varepsilon^g) < q$. This inequality ensures that if the banks' portfolios are diversified, a mixed portfolio return outcome favoring a bank can always result in liquidation by the other bank. It follows that, in either period, the probability of liquidation by at least one of the two banks always is positive.

For our baseline example, we choose $q = \frac{5}{8}$; it is clear that both versions of the example satisfy these two assumptions.

[10] These two assumptions, taken together, impose a joint restriction on θ and q. For $\theta = 0$, it is clear that $(1-\theta)(g-\varepsilon^g)+\theta(b-\varepsilon^b) > \theta(g+\varepsilon^g)+(1-\theta)(b-\varepsilon^b)$, but the inequality is necessarily reversed for an interval of θ-values below 1/2. In addition, it can be shown that if θ is below but sufficiently close to $\frac{1}{2}$, there are q-values satisfying both $(1-\theta)(g-\varepsilon^g)+\theta(b-\varepsilon^b) < q < \theta(g+\varepsilon^g)+(1-\theta)(b-\varepsilon^b)$ and $b+\varepsilon^b < q < g-\varepsilon^g$.

Table 2
Sequence of decisions.

Period 1	Period 2
Beginning of period	**Beginning of period**
Depositor decision: Manager replacement	***Depositor decision: Manager replacement***
Information used: Returns on banks' period-0 deposits (both relatively high)	*Information used*: Returns on banks' period-1 deposits
How it is made: Infer base loan returns from deposit returns (both can be inferred to have been good)	*How it is made*: Try to infer base loan returns from deposit returns
Deposits accepted	They can be inferred to be good ⇒ retain incumbent managers [Other bank's incumbents may be retained or replaced]
	They can be inferred to be bad ⇒ replace incumbent managers [Other bank's incumbents are retained]
	Good/bad returns equally likely ⇒ replace incumbent managers [Other bank's incumbents also replaced]
	Deposits accepted
***Manager decisions*:**	***Manager decisions*:**
1. ***Choice of diversification regime*** (possibly limited by regulation)	1. ***Choice of diversification regime*** (unregulated)
Information used: Base returns on loans from preceding period (known by managers to have been good)	*Information used*: Base returns on loans from preceding period
How it is made: Managers infer their competence from base returns, calculate depositor expected utility, and choose the most extensive regime providing mutual marginal benefit	*How it is made*: Managers infer their competence/not from base returns and/or replacement decisions, calculate depositor expected utility, and choose the most extensive regime providing mutual marginal benefit
2. ***Which projects to fund***	2. ***Which projects to fund***
How it is made: Using managers' risk assessment ability (or lack of)	*How it is made*: Using managers' risk assessment ability (or lack of)
Middle of period	**Middle of period**
***Depositor/manager decisions*:** Deposit withdrawal and loan liquidation	***Depositor/manager decisions*:** Deposit withdrawal and loan liquidation
Information used: Realization of interim signal (favorable or not)	*Information used*: Realization of interim signal (favorable or not)
How it is made: Depositors withdraw if signal is unfavorable; managers liquidate loans to fund withdrawals	*How it is made*: Depositors withdraw if signal is unfavorable; managers liquidate loans to fund withdrawals
Deposits may be withdrawn and loans liquidated	Deposits may be withdrawn and loans liquidated
End of period	**End of period**
Loan portfolio returns observed and deposit returns paid	Loan portfolio returns observed and deposit returns paid

End of model time

3.5. Remarks

Our model has features in common with those presented in several of the papers described in our introduction, including and especially the two Wagner papers. These features include two banks with equal-measure continua of short-horizon depositors, simple loan/investment projects with risky returns and a liquidation option, the possibility of asset portfolio diversification across the two banks, and the possibility that such diversification can lead to problematic liquidations. There are two key differences between our model and these others. One is the relationship between the loan return outcome distributions and the risk-assessment skills of the loan originators; the other is the tendency of information problems associated with diversification to make it difficult to infer the competence of the originators from the observed loan returns. Another very important difference is the dynamic nature of our model: We have two successive periods (rounds) of loan extension and liquidation and/or return realization. This dynamic element makes the ability to infer the risk-assessment skills of loan originators important. Unskilled originators should be replaced, but skilled originators should not be. If information problems cause actual replacement decisions to be inconsistent with these principles, they produce relatively unfavorable loan return outcomes in the second period.

4. Constructing an equilibrium

An equilibrium in this model involves decisions by bank depositors and bank managers. These decisions depend critically on the information available to these agents at the time they are made. At the beginning of each period, each bank's depositors must decide whether to replace or retain the bank's incumbent managers. In period 1, this decision is easy: Both banks' managers are competent and experienced, and it would not make sense to replace them. In period, 2 it may be difficult, because a bank's depositors may not have complete information about the competence of their bank's incumbent managers.

Each period, the first decision the retained or newly hired managers must make is the degree to which the banks' loan portfolios will be interconnected. In period 2, this decision depends partly on the banks' loan return outcomes from period 1, which influence the competence and experience of each bank's managers. Later, each bank's depositors must choose whether to withdraw their deposits; these decisions depend on the identity of the interim signals. If a bank's deposits are withdrawn then its managers must liquidate the bank's loans. If the two banks are interconnected, the manager-replacement decision in period 2 may be complicated by the nature of the banks' total loan portfolio return (and deposit payoff) outcomes from period 1. It may not be possible to use those outcomes to infer which bank's incumbent managers made bad loans and are now incompetent, because both banks' return outcomes are the same (under CD) and/or because liquidation by both banks may have destroyed the return information that could have been used for that purpose (under PD).

A timeline of events and decisions in the model is presented in Table 2 above.

4.1. Information

All agents in the model know the law of motion for manager competence and experience, the loan return distribution, the return from liquidation, the nature of the interim signal, the return implications of the possible diversification regimes and the roles and motives of the other agents.

The diversification decisions made by the managers of the two banks are publicly observable, as are the amounts the banks pay their depositors at the end of each period (their loan portfolio returns). Consequently, depositors and managers in period 2 know this information for period 1.

Each period, the interim signal about a bank's total loan returns is observed only by the depositors and managers of that bank, as is their liquidation decision. At the beginning of period 2, a bank's new depositors know only as much about the competence of the bank's incumbent managers as they can infer from their knowledge of the diversification regime in period 1 and the returns paid to the two banks' period-1 depositors. A bank's incumbent managers know whether they made good loans during the preceding period and whether the depositors of the banks can infer this information. As we shall see, however, in situations in which the depositors cannot infer it, the managers cannot reveal it credibly. In addition, although there is no period 0, we assume that in period 1, both banks' managers and depositors know that the managers of both banks are competent and experienced.

A key information assumption of our model is that a bank's depositors do not observe the returns on the loans originated by either bank: They observe only the banks' portfolio returns. While this assumption may seem strong, it reflects the widely held view (described in our introduction) that the fact that bank loan portfolios often included many loans originated by other banks made it difficult for financial market participants to determine the value of the portfolios, which in turn made it difficult for banks to attract or retain funds during the recent financial crisis. This situation may also have had the effect of making it difficult for the market to determine whether a bank's managers had competently assessed the risks on the loans they originated. The purpose of this paper is to explain why portfolio opacity from this source may have had these two effects and what the consequences of these effects may have been.

4.2. The liquidation decision

Our liquidation assumptions are constructed with an eye to ensuring that a bank's depositors withdraw all their deposits, and its managers liquidate the bank's entire loan portfolio, if the interim signal is unfavorable, and that no deposits are withdrawn or loans liquidated otherwise.

The assumption that the managers of a bank cannot control which loans they liquidate—that is, that they liquidate loans they originated and those the managers of the other bank originated in the proportions they represent in the bank's portfolio—is important for this purpose. Otherwise, there are situations in which the depositors of a bank might not choose to withdraw their deposits, in response to a bad signal, because they expect the bank's managers to liquidate only the loans in its portfolio that were originated by one of the two banks. They might do this because the information available to them suggests that it is relatively likely that the loans originated by the managers of one of the banks are bad. In some cases, a bank might want to liquidate only loans originated by its own managers; in others, only the loans originated by the managers of the other bank. These possibilities would reduce the severity of the problem of inefficient liquidation and, in some cases, increase the ability of period-2 depositors to infer the competence or incompetence of their bank's incumbent managers.

We see the assumption that bank managers cannot choose which loans to liquidate as related to the assumption that bank depositors cannot observe the returns on loans by originator. Both assumptions are part of the thematic assumption of our model, which is that interconnectedness (loan portfolio diversification) obscures information about the contents of bank loan portfolios. In this case, we imagine that the managers need to liquidate loans in a hurry and that collecting reliable information about the originators of particular loans might take a good deal of time. We think the idea that there may be informational distance between bank managers and risk assessors/loan originators, which we mentioned in our introduction, makes this assumption seem more plausible. Broadly speaking, this was the type of situation many financial institutions faced at the beginning of the financial crisis: They were under tremendous pressure from depositors and/or holders of other short-term liabilities to pay off those liabilities, and they needed to liquidate whatever assets they could to meet those demands.[11]

Across the two diversification regimes that feature bank interconnectedness, seeing the bad signal never allows a bank's depositors or managers to infer with certainty that either bank's managers made bad loans. Stated differently, even if a bank's managers could identify and liquidate loans by originator, if they adopted a policy of declining to liquidate loans after receiving the unfavorable signal then they would always liquidate all the loans in their portfolios only if it was certain the loans were good. For either of the two regimes that include loan portfolio diversification, our return assumptions imply that if the base loan return outcome is mixed, so that liquidation by at least one bank is possible, it is always possible for a bank that made good loans to get a no-liquidation portfolio return lower than q, and for a bank that made bad loans to get one higher than q.

[11] This assumption is inspired by, and arguably related to, the "sequential service constraint" commonly imposed in the literature on bank runs and deposit insurance. That constraint was first used by Diamond and Dybvig (1983), a seminal contribution to that literature. In their analysis, there are bank-run equilibria in which depositors who do not need to withdraw their deposits before the investment projects are completed choose to do so because if they do not, the bank may have no projects left at the end of the period, having liquidated all of them to pay off other "running" depositors. If a bank can wait to pay off individual depositors until it sees how many depositors decide to withdraw early, there can be no run equilibria. In our case, if a bank could wait to liquidate loans until it had determined which loans had been originated by which banks' managers then general liquidation might not occur. For a more extended critique of the sequential service constraint, see Wallace (1988).

Because the signal-conditional probability that a bank made good or bad loans is never 1, allowing banks to liquidate loans according to the originator would not eliminate inefficient liquidation. In addition, in our baseline example a bank's managers could not use liquidation by originator to signal their probable competence. In period 1, when both banks' managers are competent and experienced by assumption, if a bank receives the unfavorable signal and knows one bank's managers made bad loans, then in Version 1 of our example there is a 50 percent chance that its managers are the culprits; in Version 2, the figure is 67 percent. While this is not always true for other competence/experience combinations, those combinations arise only in period 2, when signaling probable competence is not useful because there is no period 3 in which to replace bank managers.

To avoid complications resulting from the facts that the depositors are risk averse, and that individual loans must have good or bad base returns, we define the liquidation component of our equilibrium in the following way. *We assume all depositors liquidate (or do not liquidate) their deposits in response to the unfavorable (or favorable) sign if an individual depositor, who observed that all the depositors except for a small positive-measure group had liquidated (or not liquidated), would decline to join this small group.* Under this assumption, it is clear that a depositor who sees the unfavorable signal will liquidate: If they liquidates, it is certain they will get a return of exactly q, and if they do not, they will get a return less than q. Similarly, a depositor who sees the favorable signal will not liquidate, because declining to liquidate will guarantee a return that exceeds q.

An important feature of liquidation of a bank's loans, in our model, is that it destroys information that would otherwise have been available to the depositors of the two banks in the next period. When a bank liquidates its loans, the total return outcome for those loans is not realized. In many cases—particularly when both banks liquidate—inferences about the competence of the banks' managers that could have been drawn from observing the resulting deposit returns cannot be drawn by observing the different returns that result from liquidation. Thus, liquidation in period 1 imposes an external cost on period-2 depositors. It benefits the period-1 depositors, in most cases, even when some of it is inefficient. However, it may destroy information that would have allowed their successors to make better management retention/replacement decisions.

4.3. The diversification decision

Each period, the managers of the two banks make a portfolio diversification decision, collectively choosing ND, PD, or CD. Although they make this decision after the depositors make their manager retention/replacement decision, the depositors make that decision in light of their knowledge of the diversification decisions managers will make under various scenarios involving their experience and competence.

We assume that a bank's managers make their diversification decisions to maximize the expected utility of its depositors. If there is disagreement about the desired degree of diversification—which can be the case if the two sets of managers are competent and have different levels of experience, or if one set is not competent—they choose the most extensive degree of diversification that provides a marginal benefit to both, relative to the next most extensive degree. For example, if one set of managers prefers PD to ND or CD, and the other set prefers CD to PD and PD to ND, both sets choose PD.

As indicated, we assume that the managers of each bank know whether they made bad loans during the preceding period, although they may not be able to reveal this information credibly to the bank's depositors. It follows that at the time they make the diversification decision, the managers of each bank know the experience/competence characteristics of the managers of both banks: They can infer this information from knowledge of their own competence and the observed deposit returns. If one bank's managers are incompetent, the other bank's managers will always decline to diversify with them, and the diversification regime will be ND. This situation can occur only in period 2, and only in situations in which the depositors of the two banks know that one set of current managers was incompetent, in the previous period, but cannot determine which one. In our baseline example, it does not occur in equilibrium, because in such a situation, both banks' incumbent managers are replaced. Otherwise, the extent of diversification depends on the return distributions, the competence characteristics of the managers, and the depositors' degree of risk aversion.

In our baseline example, if both banks' managers are experienced then CD is the best choice for any degree of depositor risk aversion. Thus, if the banks are unregulated then CD always prevails in period 1. In addition, it always prevails in period 2 regardless of regulation (which does not constrain the banks in period 2) if the period-1 base return outcome was pure, so that both banks' managers remain competent and experienced. When one bank's managers are experienced and the other bank's are inexperienced, the choice is ND in both versions of the baseline example if the depositors are weakly risk averse; if they are moderately risk averse, the choice is CD in Version 1 but ND in Version 2; if they are strongly risk averse, it is CD again in Version 1 but PD in Version 2. If both banks' managers are inexperienced then they choose ND in both versions of the example if the depositors are weakly risk averse, and CD in both version if they are moderately or strongly risk averse.

4.4. The firing (manager replacement) decision

At the beginning of each period, the depositor/owners of each of the two banks must decide whether to retain or replace (fire) the bank's incumbent managers. They will replace the managers if doing so increases their expected utility. Again, this decision is potentially difficult only for period 2.

Clearly, a bank's managers should be retained if they are competent and replaced if they are incompetent. Unfortunately, a bank's depositors cannot always be certain whether the bank's incumbent managers are competent. The reason for this is that depositors cannot observe manager competence directly; they can only infer it from the banks' past return performance.

Our assumptions guarantee that a bank's depositors will retain its incumbent managers if they are certain these managers originated good loans in the previous period, and that they will replace its incumbent managers if they are certain the managers made bad loans.

As we shall see, the only other possibility is that they are uncertain, in the sense that it is equally likely that the incumbent managers originated good loans or bad loans in the previous period.

4.4.1. When is the period-2 retention/replacement decision difficult?

As we have seen, the information the period-2 depositors have to assess the qualifications of their banks' incumbent managers includes the structure of the model, the nature of the diversification regime in period 1, and the return received by each bank's depositors in period 1. They do not directly observe the returns on the loans originated by either bank's managers. They know whether either bank liquidated its assets in period 1 because the bank's depositors received a return equal to the liquidation value.

We now turn to the question of which period-1 return outcomes produce which manager experience situations in period 2 after the manager retention/replacement decisions have been made: two sets of experienced managers, one set, or no sets. In both the latter cases, the other set of managers is inexperienced.

If the joint return outcome from period 1 was pure, so that both banks' managers were competent, the depositors of both banks can infer that fact from the period-1 deposit returns, regardless of the diversification regime. Regardless of the diversification regime, no pure joint return outcome can produce a deposit return, for either bank, as small as the largest possible deposit return associated with a mixed joint return outcome. If the joint return outcome from period 1 was mixed and the diversification regime was ND, the depositors know immediately which bank's managers were incompetent: it is the managers of the bank that paid the lower return. The same thing is readily seen to be true under PD, provided both banks did not liquidate their asset portfolios.

Thus, there are two combinations of diversification regime and joint loan return outcome that produce uncertainty about manager competence. Under PD, it is any joint mixed return outcome that produces portfolio liquidation by both banks. Under CD, it is any joint mixed return outcome of any sort, regardless of liquidation, because the depositors of both banks always receive the same return. In any of these cases, the return outcome is known to have been mixed, so the depositors of both banks know that the managers of one of the two banks were incompetent. However, since the two portfolio return outcomes were identical, they have no way of knowing which bank it was.[12] In the first version of our first baseline example, when the banks are interconnected, they both fail whenever there is a mixed outcome with a low shock to the good base return, regardless of the diversification regime. In the second version, however, only one bank fails under PD, if a low shock to the good base return is accompanied by a high shock to the bad one.

4.4.2. How the decision is made when it is difficult

If the deposit returns from period 1 do not reveal which bank's incumbent managers (if either) turned out to be incompetent, we model the period-2 manager-replacement decision as a non-cooperative game between the depositors of the two banks. The rationale for this approach is that the distribution of return outcomes resulting from a manager-replacement decision by one bank may depend on the manager-replacement decision of the other bank. We assume each bank's depositors make the replacement decision that produces a return distribution that maximizes their expected utility, given the replacement decision they expect the other bank to make. We stick to pure strategies: replace or not, as opposed to some probability of replacement. In addition, we look for return assumptions that will produce an equilibrium in which the managers of both banks are replaced.

As we have indicated, we assume that a bank's incumbent managers know their risk-assessment performance from the previous period: whether they made good loans or not. *However, if they made bad loans in the previous period and that fact cannot be inferred from the banks' deposit returns, they do not reveal it, because they lose satisfaction from being shown to be incompetent*. This is the one situation in which a bank's managers make a decision that is not in the interest of the bank's depositors. It follows that the incumbent managers of the other bank, who made good loans, cannot credibly reveal their competence. Finally, we assume manager replacement is publicly observed, so that the current managers of each bank (incumbents or replacements) know whether the current managers of the other bank are inexperienced.

4.4.3. Looking for an equilibrium in which both banks fire their managers

Suppose the depositors of Bank B (for example) choose to replace its managers, so that its new managers are inexperienced. If the depositors of Bank A also replace its managers, then both banks have inexperienced managers. The resulting return distribution will depend on whether the inexperienced managers of one bank choose to diversify their bank's portfolio with that of another bank with inexperienced managers, and, if so, to what degree they choose to diversify: see above.

If the depositors of Bank A do not replace its managers then one of two scenarios follows. If Bank A's managers are incompetent, Bank B's managers will not agree to diversify with it. Bank A's depositors are certain to receive a low base return, and Bank B's depositors will face the marginal return distribution for loans made by inexperienced managers. Otherwise, Bank A's managers are experienced. What happens next depends on whether and to what extent experienced managers choose to diversify their loan portfolios with loans made by inexperienced managers: again, see above.

For a given level of intensity of depositor risk aversion, consider the expected utility received by a bank with inexperienced managers when the managers of the other bank are also inexperienced (*eu-ii*). If this value exceeds the average of the expected utility

[12] Obviously, CD is very special, in this sense: In cases in which both banks do not liquidate, even a tiny departure from a 50-50 portfolio split would create differences between the joint returns received by the two banks, allowing depositors to infer the identity of the bank that originated bad loans. We choose CD as one of our three regimes because we think of the model presented here as a proxy for a more complicated model with additional sources of continuously distributed noise affecting the return distributions. In such a model, a diversification regime close to CD would make inference about the identity of the bank that made the bad loans very unreliable.

Table 3

Incipient base return outcome (Period 1)	Liquidation (Period 1)	Inference for total return (Periods 1-2)	Manager replacement (Period 2)
Joint pure $p^{ee} = 1/2$ (any diversification regime)	None (neither bank) $p = 1/2$	Both base returns good Both banks' managers competent	Both incumbent managers retained *ee* Both competent and experienced
Joint mixed $p^{ei} = 1/2$			
ND	One bank $p = 1/2$	That bank's base return bad; its managers incompetent Other bank's base return good; its managers competent	Incumbent managers replaced, competent but inexperienced *ei* Incumbent managers retained, competent and experienced
			ND: *p-ee* 1/2, *p-ei* 1/2
PD	Neither bank $p_1 = 1/4$ $p_2 = 1/4$	High-return bank's base return good; its managers competent Low-return bank's base return bad; its managers incompetent	Incumbent managers retained, competent and experienced *ei* Incumbent managers replaced, competent but inexperienced
	One bank $p_1 = 0$ $p_2 = 1/8$	That bank's base return bad; its managers incompetent Other bank's base return good; its managers competent	Incumbent managers replaced *ei* Incumbent managers retained
	Both banks $p_1 = 1/4$ $p_2 = 1/8$	One bank's base return bad: not clear which	Both banks' managers replaced; both competent but inexperienced *ii*
			PD: p_1-*ee* 1/2, p_1-*ei* 1/4, p_1-*ii* 1/4 p_2-*ee* 1/2, p_2-*ei* 3/8, p_2-*ii* 1/8
CD	Neither bank $p_1 = 1/4$ $p_2 = 1/4$	One bank's base return bad: not clear which	Both banks' managers replaced; both competent but inexperienced *ii*
	Both banks $p_1 = 1/4$ $p_2 = 1/4$	One bank's base return bad: not clear which	Both banks' managers replaced; both competent but inexperienced *ii*
			CD: *p-ee* 1/2, *p-ii* 1/2

received by a bank with incompetent managers (*eu-n*) and that received by a bank with experienced managers when the managers of the other bank are inexperienced (*eu-ei*), the result is a Nash equilibrium in which both banks replace their managers. This is true in both versions of our baseline example.

In Appendix A, we describe a process that can be used to check the uniqueness of this equilibrium. It is unique in both versions of our baseline example.

The complications associated with risk aversion make it impossible for us to provide a general characterization of the specifications in which the equilibrium in which both banks replace their managers in period 2, when the competence of the incumbent managers is unknown, is unique. In what follows, we will assume the specification has this property.

For our baseline example, a summary of the relationship between loan return and liquidation outcomes in period 1 and manager retention/replacement outcomes in period 2 is presented in Table 3 above. In the table, a 1-subscript indicates a probability in Version 1 of the example and a 2-subscript indicates a probability in Version 2.

4.5. Optimal bank regulation

We assume the government's goal is to maximize the average *ex ante* expected utility of period 1 and 2 depositors, under the assumption that depositors do not know which bank they will be associated with. As we have seen, in period 1, the depositors of each bank are assumed to act to maximize their expected utility, ignoring the fact that their actions (and the actions bank managers take on their behalf) affect the outlook for depositors in period 2. This situation creates a possible rationale for government intervention in period 1. There is no such rationale in period 2, when the interests of the government and the depositors are aligned. We assume the government has a simple set of regulatory options in period 1: It can do nothing, in which case the managers of the banks will choose the diversification regime that maximizes the utility of their period-1 depositors, or it can restrict banks' degree of diversification by ruling out one or two of the three diversification regimes. For example, if the banks prefer CD in period 1, the government can rule out CD, allowing the banks to choose PD or ND, or it can rule out both CD and PD, forcing them to choose ND. In period 2, the managers of the banks are free to choose the diversification regime that maximizes the expected utility of their depositors.

We begin by choosing a particular level of intensity of risk aversion, which is assumed to be shared by all the depositors. Next, we determine the *ex ante* expected utility of a depositor of this type in the absence of government regulation. We assume that the depositor may live either in period 1 or in period 2, and, in either case, that her deposits may be in either bank. We also assume, for the purposes of this discussion, that if there is a mixed joint return outcome in period 1 and the identity of the bank whose managers made the bad loans cannot be determined, the managers of both banks are replaced (see above).

Absent regulation, the banks in period 1 choose the diversification regime that maximizes the expected utility of the period-1 depositors. Because of the potential losses from inefficient liquidation (liquidation of loans that turn out to be good or non-liquidation of loans that turn out to be bad), this regime is not necessarily CD, although it is CD in our baseline example. The choice of the diversification regime in period 1 determines the probabilities of the three possible states in period 2: a state in which both sets of managers are experienced, a state in which one set of managers is experienced and the other set is inexperienced, and a state in which both sets of managers are inexperienced. In the case of a Nash equilibrium with replacement (see above), there is no state in which either set of managers is incompetent.

Next, we work out the return distribution received by the depositors of each bank in each of these states, given that a bank's managers in period 2 choose the degree of diversification that is optimal for their period-2 depositors. As there is no period 3, there is no reason for the government to choose a diversification regime that is different from the one the banks' managers (and, thus, the depositors) would choose. We can determine depositors' expected utility in each state from the return distributions. Note that in the experienced-inexperienced state, we must average the expected utility received by the depositors of the bank with experienced managers and that of the depositors of the other bank. In the other two states, the depositors of both banks get the same expected utility.

The government may prefer less diversification in period 1 than happens absent regulation because of the external costs that complete or partial diversification may impose on period-2 depositors. In these cases, there is a welfare rationale for government regulation that limits or even prohibits diversification (interconnectedness).

4.6. Characterizing equilibria

In this model, an equilibrium is a description of the distribution of the return outcomes for the depositors in periods 1 and 2, given our assumptions (including those about the behavior of the agents in the model).

In period 1, the depositors of both banks make a trivial manager replacement/retention decision: both banks' depositors retain their incumbent managers. The managers choose the diversification regime that maximizes the expected utility of their depositors, given the constraints that may be imposed by the government, which may prohibit diversification (imposing ND) or limit diversification (prohibiting CD). In the middle of the period, the depositors of a bank withdraw their deposits, and the bank's managers liquidate its loans, if they get the unfavorable signal about the bank. At the end of the period, the banks pay out returns to the depositors.

At the beginning of period 2, the new depositors of both banks observe the returns received by the depositors of the banks in the previous period, along with the diversification regime chosen by those banks' managers. The new depositors then make their manager replacement decisions. Each bank's depositors make the decision (retain or replace) that maximizes the expected utility of their returns. These decisions are influenced by the depositors' knowledge of whether and how much the managers of the two banks will choose to diversify the banks' loan portfolios, under various scenarios involving their competence and experience. The events of the rest of the period proceed as in period 1, except that there are no government-imposed constraints on the managers' diversification decisions—regardless of whether such constraints were present in period 1—and the economy ends at the end of the period.

The key difference between period 1 and period 2 is that, in period 2, one bank may have experienced managers while the other bank has inexperienced managers, or both banks may have inexperienced managers. Assuming, as we continue to do, that the depositors know that one set of incumbent managers is incompetent, but do not know which one, they replace both sets.

4.7. Interpretations and assumptions

As we explained in our introduction, the motivation for our analysis involves, in large part, some widely held beliefs about the length and severity of economic recessions. Thus, we need to identify the outcomes in our model that represent recessions. Since loan returns are the only output in the model, we think of the total loan return in a period across the portfolios of the two banks as the total output for the period.

For our purposes, periods in which one of the base loan return outcomes is bad are recession periods. In these periods, the total loan return is significantly below average, and one of the banks has made bad lending decisions.[13] Thus, in this model, the cause of recessions is bad lending decisions by banks. It should be noted, however, that when there are two low shocks, good lending decisions by both banks can produce a total loan return that is lower than the total return in some recessions. Recessions vary in severity because of the shocks to the base return outcomes. They also vary in severity across diversification regimes, because diversification produces inefficient liquidation decisions. Whenever a diversified portfolio is liquidated during a recession, some loans that would have yielded

[13] A bank with a portfolio that includes loans with bad base returns may or may not actually receive the returns on those loans, because it may liquidate its portfolio. However, we say a recession has occurred whenever the base returns on the loans originated by one of the two banks are bad, whether or not either bank receives those returns.

a total return in excess of the liquidation value are liquidated, reducing output. Whenever a diversified portfolio is not liquidated during a recession, some loans that will yield a total return below the liquidation value are not liquidated: Again, output is reduced.

We think of periods in which at least one bank liquidates its asset portfolio (fails) as periods of financial crisis. A financial crisis can occur only during a recession. When banks diversify their asset portfolios, however, a recession may not always produce a financial crisis.

If both banks liquidate their asset portfolios, we say the financial crisis is severe. The resulting total loan return is lower than any other total return that can occur in the model, so periods in which double-liquidation occurs are also called periods of severe recession. As we have seen, severe crises and severe recessions can occur only when the banks' portfolios are diversified, so we characterize them as systemic in origin. This feature of the model is a consequence of our assumption that, in any period, if both sets of bank managers are competent (made good loans in the previous period, or are new to bank management), then at most one set of loans turns out to be bad. This assumption is made largely for analytical clarity. We have constructed the model so that severe crises may be caused by bank interconnectedness; this assumption prevents us from having to distinguish severe crises caused by interconnectedness from severe crises that might have occurred without it.

The sequential structure of the model introduces a very simple exogenous business cycle. On average, output in period 1 is higher than in period 2. The reason for this is that the economy begins, in period 1, with two sets of experienced bank managers, so the probability of a recession is relatively low.[14] However, a recession in period 1 always increases the probability of a recession in period 2: It indicates that one set of bank managers was incompetent, leading to the replacement of one or both sets of managers.

When the banks' portfolios are diversified in period 1, the effect of a period-1 recession on the probability of a period-2 recession is magnified, because some recessions cause both sets of managers to be replaced. The increased probability of a period-2 recession also increases the probability of a systemic crisis, which produces the most severe type of recession. Thus, in our model, interconnectedness among banks increases the frequency of recessions in period 2, the average severity of recessions in both periods, and the average length of recessions (that is, the probability of consecutive recessions).

In our business cycle interpretation, period 1 represents a period when the economic outlook is relatively favorable, but in which problems can occur that will make the outlook for the next period much less favorable. The government's goal, as we shall see, is to regulate the banking system, during this period, in a way that makes the economy's prospects in the following period less unfavorable, increasing depositors' average expected utility across the two periods.

5. The baseline example

A more detailed description of certain aspects of this example is presented in Appendix B. Here, we summarize some of its important properties, which we determine by using the parameters from the example to obtain the marginal and joint return distributions for each of the three possible numbers of experienced managers (two, one, or zero) and each of the three possible diversification regimes. We can then determine the structure of the equilibrium return-outcomes distribution across both periods if there is no government regulation, and we can determine which diversification regime the government will impose in period 1 if there is regulation. We can also calculate various summary measures of this outcomes distribution. As we have seen, the nature of the distribution—and thus, the values of the summary measures—may depend on depositors' degree of risk aversion, which influences both the diversification decisions of the banks' managers and the regulation decisions of the government.

5.1. Specification

As we have seen, the two versions of the example differ only in that, in the first version, there are no random shocks to the bad base return. The good base loan return outcome is 1 and the bad outcome is 1/2. The shock to the good base return is $\pm 1/3$, and, in Version 2, the shock to the bad return is $\pm 1/12$. The liquidation value is 5/8.

If a bank's managers are competent and experienced, the probability that they will make good loans is 3/4; if they are competent but inexperienced, it falls to 1/2. If one bank's managers are experienced and the other bank's managers are inexperienced then in the event of a mixed outcome there is a 2/3 probability that the experienced managers will be the ones who originated the good loans. Given our assumption that at least one among two sets of competent managers always originates good loans, it follows that if both sets of bank managers are competent and experienced then the probability they will both originate good loans is 1/2. This probability falls to 1/4 if one set of managers is inexperienced and to 0 if both sets are inexperienced.

Finally, under partial diversification, one-third of each bank's asset portfolio consists of loans originated by the other bank.

Clearly, the magnitude of certain important features of the model has been exaggerated to make it easier to identify their roles. The probability of a recession in period 1, which is entirely exogenous, has been set very high (50 percent), and our assumptions imply that the output loss from a recession is always on the order of 20 percent of the non-recession output. These features tend to increase the benefits from government intervention to limit diversification, which, as we shall see, can reduce the frequency of recessions and, to a lesser extent, their output costs. On the other hand, the variation in the base returns is very large: The bad return is only half the size of the good return. The shocks around the base returns are also quite large—the shock to the good base return is

[14] In a multi-period version of the model, the unconditional probability of entering a period with two experienced managers would be higher than the other possibilities, so there would still be a type of business cycle. However, such a version would be more difficult to analyze, partly because the government might have an incentive to regulate interconnectedness even when one or fewer sets of managers was experienced.

one-third as large as that return. In addition, in Version 2 of the example, where there are shocks to the bad base return, these shocks are a sixth as large as that return. These features tend to increase the costs of government intervention to limit diversification, since they create the possibility of large welfare gains from risk spreading.

The question of the choice of the three diversification regimes also deserves some comment. Choosing complete diversification ($\theta_3 = \frac{1}{2}$) as one of the regimes—a feature of the model, not just the baseline example—is, in a sense, natural, since it provides the maximum portfolio-diversification benefits to depositors. On the other hand, it is very special: Both banks have identical portfolios, making it impossible to draw any differential competence inferences from loan return outcomes if both banks' managers are the same type. Then again, this is a model in which drawing inferences from loan return observations seems vastly easier than would be likely in practice, because there are so few sources of uncertainty and the number of possible return outcomes is so limited. It seems to us that in any practical situation in which loan portfolios were very substantially diversified, even if the diversification was not complete, drawing inferences from loan returns would be extremely difficult.

The choice $\theta_2 = \frac{1}{3}$ for our baseline example also seems natural, since it is, in a sense, midway between complete diversification and no diversification. In a more general and sophisticated version of this model in which the two banks were free to choose any mutually acceptable degree of diversification, we might expect them to choose the degree partly with an eye toward making inferences of various sorts easier. Again, however, it seems to us that that would be possible only because the very simple return assumptions of the model make inference much easier than it would be in practice.

Given these choices, structuring an example that has the properties we describe below is actually fairly easy. The starting point is to choose q by

$$q = \frac{1}{2}(g - \varepsilon^g) + \frac{1}{2}\left(b + \varepsilon^b\right),$$

where ε^b is the (positive) value from Version 2 of the example in question. Note that this choice is consistent with Assumption 1b above. It follows that under CD, both banks liquidate their loan portfolios whenever there is a mixed base loan return outcome (so that the managers of one of the banks made bad loans) and the random shock to the return on the good loans is low, regardless of which bank made the bad loans or which shock outcome of those loan returns is realized. This is true in both versions of the example. Since $\theta < \frac{1}{2}$ by assumption, it also follows for q that $(1-\theta)(b+\varepsilon^b) + \theta(g-\varepsilon^g) < q$ for any legitimate choice for θ, including $\theta = \frac{1}{3}$ as in the example, and that $(1-\theta)(g-\varepsilon^g) + \theta(b+\varepsilon^b) > q$. The first inequality implies that under PD, if there is a mixed outcome and the realized shock to the good loans is low, the bank with managers who made bad loans liquidates; the second inequality implies that the other bank does not liquidate. Finally, these two inequalities imply $(1-\theta)(b-\varepsilon^b) + \theta(g-\varepsilon^g) < q$ and $(1-\theta)(g-\varepsilon^g) + \theta(b+\varepsilon^b) < q$, so that, under PD, both banks will liquidate if there is a mixed outcome and both shock realizations are low (Version 2) or the good-return shock realization is low (Version 1).

This choice for q also implies $\frac{1}{2}(g+\varepsilon^g) + \frac{1}{2}(b-\varepsilon^b) > q$, so that, under CD, a mixed outcome never results in liquidation when the realized shock to the good base return is high. The right-hand side of Assumption 2 guarantees the same thing for PD. The left-hand side of Assumption 2 guarantees that it's always possible for a mixed outcome featuring a low shock to the good base return to produce liquidation, and that under the Version-1 assumption (no shocks to the bad base return), it always does so.

Thus, we have identified assumptions that ensure that, under CD, both banks liquidate whenever there is a mixed return outcome featuring a low shock to the good return, and neither bank liquidates in any other situation. Under PD, a mixed return outcome with a low shock to the good return causes liquidation by one bank if the shock to the bad return is high and liquidation by both banks if that shock is low or there are no bad-return shocks.

When both banks liquidate in period 1 they will have inexperienced managers in period 2. When one bank liquidates, or when no bank liquidates but one bank made bad loans, that bank's managers will be inexperienced and the other bank's will be experienced. Otherwise, both banks will have experienced managers. Note that the assumption necessary to ensure that both banks' managers are replaced after both banks liquidate—in which case neither bank's depositors can infer that its incumbent managers are probably competent—is basically that the bad base return is sufficiently low relative to the good return, so that it is always a bad idea to take the risk that your bank's managers will turn out to be incompetent. The assumption necessary to ensure that banks strongly prefer to diversify their portfolios, so that government regulation to restrict period-1 diversification may be desirable, is that random shocks to the relatively-probable good loan returns are large relative to their base values. Thus, after choosing $g = 1$ for purposes of normalization, we choose $b = 1/2$ rather than something larger and $\varepsilon^g = 1/3$ rather than something smaller. Note that a large value for ε^g relative to ε^b also is necessary for the right-hand-side inequality from Assumption 2 to be satisfied.

Clearly, the choice of q we use for our examples is special, but slightly higher values would not change the nature of the examples materially as long as Assumption 1b is satisfied.

5.2. *Laissez faire (LF) equilibria*

In the absence of government regulation, the diversification regime chosen by the banks' managers in period 1 is CD, regardless of depositors' degree of risk aversion. The welfare benefits from risk spreading more than offset the costs from inefficient liquidation, even when the depositors are only weakly risk averse.

In period 1, expected output per depositor in period 1 is 11.5 percent below normal (expected non-recession) output per depositor, which is 1 (we will drop "per depositor" henceforth). There is a 50 percent probability of a recession, and output averages 22.9 percent below normal during a recession. Half the recessions are accompanied by financial crises (liquidation by a bank); all these crises are severe (involve both banks). Some recessions are not accompanied by financial crises because favorable shocks allow the banks' common portfolio return to remain above below the liquidation value, even though one set of loans is bad. All liquidations are associated with severe crises because, under CD, the two banks' loan/deposit returns are always equal.

Although liquidation does not occur in all recessions, all recessions feature inefficient liquidation decisions. In half of the recessions, loans for which return outcomes are below q are not liquidated; in the other half, loans for which return outcomes would have been below q are liquidated. Inefficient liquidation makes the average output loss in a recession (and thus, the average output loss from recessions) substantially higher than it would be otherwise.

In period 2, there is a 50 percent probability that the return outlook will be identical to the outlook in period 1, because the depositors of both banks will retain the banks' managers, so that both sets of managers will remain experienced. These events follow a pure joint return outcome in period 1. There is also 50 percent probability that the depositors of both banks will replace the banks' managers. This probability is so high because, under CD, replacement of both banks' managers always follows a mixed outcome in period 1: The two banks always pay the same return, so it is never possible to infer which bank's managers originated bad loans.

When both banks' managers are inexperienced a recession always occurs. Thus, the probability of a recession in period 2 is 75 percent. Since half of these recessions are accompanied by systemic crises, the probability of the latter rises from 25 percent in period 1 to 37.5 percent in period 2.

If the depositors are weakly risk averse, the effect of the higher probability of recession on expected output in period 2 is partly mitigated by the fact that if both banks' managers are inexperienced, they choose ND, so there are no losses from inefficient liquidation (see below). Consequently, output in a recession averages 20.1 percent less than normal, instead of 22.9 percent. Average output is in period 2 is 15.1 percent below normal output, compared to 11.5 percent in period 1.

The fact that the average return is lower in period 2 reflects the business cycle built into the model: period 2 is inherently less favorable on average, because there are always possible period-1 return outcomes that result in at least one bank having inexperienced managers in the next period. When depositors are moderately or strongly risk averse, the amplitude of the business cycle is exacerbated by the fact that the banks' managers choose CD (and with it, the possibility of inefficient liquidation) even when they are both inexperienced. In this case, output in a recession again averages 22.9 percent below normal, and average output is 17.2 percent below normal output.

The probability of a long (two-period) recession is 50 percent. In this simple example, if there is no government regulation, a recession in period 1 is always followed by a recession in period 2.

5.3. Equilibria under government regulation

If the government regulates the banking system, the results differ substantially across various degrees of depositor risk aversion and moderately across various versions of the example.

If the depositors are weakly risk averse, the government imposes ND in period 1 in both versions of the example. It does so because the period-1 depositors are not hurt much by the increase in the variability of their returns that results from eliminating diversification. Consequently, their losses are outweighed by the benefits to the period-2 depositors of a sharply reduced probability of a recession in that period. The period 1 depositors also benefit from elimination of liquidation inefficiency, though that benefit is not large enough to prevent them from being worse off, on net.

In period 1, the probability of a recession does not change, but expected output is only 9.4 percent below normal output, because expected output in a recession is only 18.8 percent below normal. The difference between this figure and the LF figures of 11.5 and 22.9 percent reflect the inefficiency of liquidation when there is diversification. Under ND, every recession features liquidation by the bank whose managers originated the bad loans (a financial crisis). However, all these loans are liquidated, and none of the other loans are, so liquidation is efficient. There is no possibility of liquidation by both banks (a systemic crisis).

No diversification (ND) in period 1 improves the outlook for period 2 by replacing the 50 percent probability that both banks will have inexperienced managers with an equal probability that only one bank will have them. Now, it is easy for period-2 depositors to identify the bank whose managers originated bad loans: It is the bank whose portfolio was liquidated. Thus, those managers are replaced, but not the others. When only one bank has inexperienced managers, the probability of a recession is only 75 percent, and the probability of a long recession falls from 50 percent to 37.5 percent because a recession in period 1 no longer guarantees a recession in the next period.

Thus, government regulation loosens the otherwise-tight link between recessions in periods 1 and 2, and it causes the unconditional probability of a recession in period 2 to fall to 62.5 percent.

The fact that the government chooses ND in period 1, in this case, allows us to use it to help identify the various disadvantages of diversification for the model economy. As we have seen, under ND, in period 1, the average output loss from recessions is only 9.4 percent, compared to 11.5 percent under LF. More importantly, however, the probability of a recession in period 2 is only 62.5 percent, compared to 75 percent under LF.

We can identify additional disadvantages of diversification by imagining what would happen if it was also prohibited in period 2. The average output loss from recessions would be 11.7 percent in that period, compared to the LF figures of 15.1 or 17.2 percent, depending on depositors' degree of risk aversion. These differences reflect both the lower probability of recessions and the elimination of inefficient liquidation. Notice that not only is the average output loss from recessions much lower in period 2 absent diversification, it also rises less steeply from period 1 to period 2—increasing by only 2.3 percentage points, compared to 3.6 or 5.7 percentage points under LF. The probability of a long recession is 37.5 percent, as above; as we have seen, when there is ND in period 1, the depositors choose ND in period 2 even if they have other options.

Returning to the question of the impact of government regulation when depositors are weakly risk averse, it turns out that, in this case, experienced managers will not diversify their loan portfolios with loans made by inexperienced managers. Diversification (CD) will occur in period 2 only when there was no recession in period 1. Average output in a recession is only 20.4 percent below normal, because three-fifths of recessions do not result in inefficient liquidation—the average level of output is only 12.8 percent below normal, compared to 15.1 percent without regulation.

Thus, when depositors are weakly risk averse, government regulation reduces both the average output cost from recessions and the average amplitude of the business cycle, though not by quite as much as they would be reduced if diversification was not possible. In addition, it reduces the probability of a long recession by exactly as much (25 percent) as it would be reduced if diversification was not possible.

If the depositors are moderately or strongly risk averse, the government restricts but does not prohibit diversification, allowing the bank managers to choose PD but not CD. Here, the benefits of diversification to the period-1 depositors are too great for the government to ignore. It can reduce the probability of recession in period 2 by restricting diversification, though not to the same extent as by prohibiting it.

Limiting diversification in period 1 is less effective at preventing recessions than prohibiting diversification, because it does not rule out the worst-case scenario for period 2: replacement of both banks' managers. However, recessions in period 2 remain less likely than under LF, because replacement of both banks' managers now occurs only if there is a systemic crisis in period 1; that is, only if both banks liquidate their portfolios. If there is no financial crisis, or if there is a non-systemic crisis—which can happen under PD, and does happen in Version 2 of the baseline example—the period-2 depositors can use the differences in the returns the period-1 depositors were paid to infer which bank's managers originated the bad loans. Under CD, there are never any such differences, whether or not the bank portfolios are liquidated. In these cases, only one bank has inexperienced managers in period 2—the same situation that follows recessions when the period-1 regime is ND.

As under LF/CD, half the recessions produce liquidation by at least one bank: a financial crisis. In Version 1 of the baseline example, all these crises are systemic: Both banks liquidate, as under LF/CD. In Version 2, however, half the crises involve liquidation by only one bank, so that only a fourth of the recessions produce systemic crises.

While there is the usual one chance in two that both banks will have experienced managers in period 2, in Version 1, there is one chance in four that only one bank will have inexperienced managers (a possibility that does not exist under LF) and one chance in four that both will have them (a possibility that does not exist when the government regulates the banks but the depositors are less risk averse). In Version 2, these figures are three chances in eight and one in eight, respectively. Consequently, in Version 1, the probability of a recession in period 2 is 11/16 (almost 0.69), compared to 0.625 when the depositors are weakly risk averse, and compared to 0.75 under LF. In Version 2, the period-2 recession probability is 21/32 (a bit more that 0.65). The probability of a long recession is 7/16 (almost 0.44) in Version 1 and 13/32 (less than 0.41) in Version 2. Thus, regulation continues to reduce the risk of long recessions substantially.

Thus, when the depositors are relatively risk averse, the relatively moderate form of regulation chosen by the government does not loosen the link between period-1 and period-2 recessions as much as it is loosened by the extreme form of regulation the government chooses when depositors are less risk averse. However, this more moderate form of regulation creates a tight link between systemic crises in period 1 and recessions in period 2. Under LF (CD in period 1), all recessions in period 1 are followed by recessions in period 2: There is nothing special about recessions that produce systemic crises. Under extreme regulation (ND in period 1), there are no systemic crises in period 1. Under moderate regulation (PD in period 1), however, there are still systemic crises in period 1 (although in Version 2, they are less common than before), and recessions that involve systemic crises are the only ones that are invariably followed by recessions in the next period.

In Version 1, the average period-1 recession reduces output by 22.9 percent, exactly as under LF. Therefore, output averages 11.5 percent below normal. In Version 2, the figures are 23.6 percent and 11.8 percent, respectively. These figures are not very different from those under LF because the extent of the inefficient liquidation is not very different under PD than under CD.

In period 2, both the extent to which the average recession reduces output and the average output cost of recessions depends on the depositors' degree of risk aversion and the version of the example. They increase as depositors become more risk averse, because there is more diversification and, thus, more inefficient liquidation. They decrease in Version 2, relative to Version 1, because in Version 2, the worst-case scenario for period 2 is less likely. The lowest figures are 21.1 percent and 13.8 percent, for depositors who are moderately risk averse and Version 2; the highest figures are 22.9 percent and 15.8 percent, for depositors who are strongly risk averse and Version 1. However, even the latter figure remains substantially lower than 17.2 percent, which is the average output loss from recessions, for these degrees of risk aversion, when there is no regulation. Thus, government regulation also moderates the business cycle and reduces the frequency of long recessions when depositors are relatively risk averse.

6. Concluding remarks

6.1. Summary

The goal of our analysis was to construct a simple theoretical model to help explain the relationship between interconnectedness of financial institutions, systemic financial crises, and long, severe recessions.

In our model, banks connect with each other by loan portfolio diversification: their portfolios include loans originated by other banks. This sort of interconnectedness is attractive to bank depositors but potentially hazardous for the banking system.

The model's key assumptions are:

- Recessions occur because banks originate bad loans, and banks originate bad loans because their managers are incompetent at risk assessment.
- Loan portfolio diversification makes it difficult for a bank's depositors to determine the returns on particular components (by originator) of the bank loan portfolio.

As a result, depositors may make inefficient decisions, of two types:

- Decisions about loan liquidation, and
- Decisions about retention or replacement of bank managers.

Inefficient loan liquidation decisions can increase the severity of recessions; they may also produce systemic financial crises. Systemic crises, in turn, contribute to creating situations in which depositors make inefficient manager replacement decisions. Inefficient replacement decisions reduce the ability of the banking system to assess credit risk, increasing the probability of long, severe recessions.

Government restrictions on interconnectedness can increase the average welfare of bank depositors. However, the optimal degree of restriction may not entirely prevent systemic financial crises or long, severe recessions.

6.2. Qualifications and extensions

Our results depend on a number of assumptions that are strong and might make some readers uncomfortable. A very basic assumption is that banks and depositors cannot directly observe loan returns by the originator: they can directly observe only loan portfolio returns. We make this assumption because we believe that the financial crisis and the subsequent severe recession were partly caused and/or exacerbated by doubts about the ability of banks to assess credit risk effectively, and we are interested in the possibility that loan-portfolio interconnectedness may have exacerbated this problem by tarring bank managers with the brush of poor performance by loans they did not originate. Assuming banks can observe portfolio returns but not returns by the originator seems like a good place to start. However, there could be less extreme ways in which the presence in bank loan portfolios of loans originated by other banks might make it harder for a bank's owners and/or depositors to draw inferences about the risk-assessment abilities of its managers.

Perhaps the strongest and most suspect assumption we make is that banks do not have the option of liquidating loans by the originator. This assumption is necessary to prevent banks from increasing their expected portfolio returns by liquidating only loans with particular originators—loans they can infer to be relatively likely to be good. As we have indicated, it is not always possible, in our model, for depositors or managers to draw inferences of that type. One solution might be to find return-distribution assumptions under which it is never possible, but that would not greatly disrupt other aspects of our results. We think that would be difficult, but it might not be impossible. An alternative might be to eliminate or deemphasize liquidation and replace it with return-distribution assumptions under which a substantial fraction of the deposit return outcomes associated with joint mixed returns would not allow the identity of the bank that made bad loans to be inferred, as is always true here under CD. We experimented with a model of this sort before we settled on the current model, and we believe the concept deserves a second look.

The fact that model time ends after two periods makes the analysis of the model much easier, partly because we do not have to worry about regulatory policy in period 2, where it would be much more complicated because a much wider variety of things can happen. However, there are only a limited number of return outcome distributions that can arise in the model, even if the number of periods is infinite. It is easy to imagine a version of the model in which the two banks have infinite "lives" and a bank's managers remain competent, period after period, as long as they continue to make good loans. In such a model, it would be possible, though probably difficult, to work out the time series and welfare implications of diversification regimes that were imposed in period 1 and remained in place in all subsequent periods. Simulation methods and appropriate summary statistics night be required.

As with many simple models with regulatory policy implications, government restrictions of the sort we are imagining might be much harder to implement in practice than they are in the context of the model. The portfolios of our banks consist entirely of loans, originated either by one bank's managers or by those of the other bank. In practice, for any bank whose assets consisted mostly of loans, it would be easy to imagine a restriction that limited the fraction of the loans originated by other banks. Things get more complicated for financial institutions that devote a substantial fraction of their asset portfolios to marketable securities: bonds or stocks. For many of these institutions, our analysis simply might not be relevant. However, if an institution's assets include large volumes of securitized loans, including but not confined to mortgage-backed securities, then we would certainly argue that holdings of these securities should be regulated in the same way as holdings of non-securitized loans originated by other banks. As we've indicated, the problems financial institutions experienced with assessing the credit risk on mortgage-backed securities, and the problems experienced by the holders of the liabilities of some of these institutions with trying to determine the value of the institutions' portfolios, and with making decisions about the disposition of the liabilities, played a key role in inspiring us to write this paper.

Declaration of Competing Interest

Marco Espinosa-Vega and Steven Russell Authors of Interconnectedness, Systemic Crises, and Recessions declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Two issues

Is the Nash equilibrium involving replacement of both sets of bank managers unique?

To show that this equilibrium is unique, we need to show that if Bank B's depositors choose not to replace its managers, it remains optimal for Bank A's depositors to replace its managers. If Bank B does not replace its managers and Bank A does (meaning that they are inexperienced), there are two possibilities. One is that Bank B's managers are incompetent. In this case, Bank A's managers will not choose to diversify with Bank B, and Bank A's depositors will get the expected utility from the inexperienced, undiversified return distribution (*eu-i*). The other possibility is that Bank B's managers are experienced. In that case, if Bank A gets *eu-ie*, the expected utility of the return distribution received by a bank with inexperienced managers, when the other bank has experienced managers. Note that the nature of this distribution depends on whether a bank with experienced managers chooses to diversify with a bank with inexperienced managers and how much.

If neither bank replaces its managers, there are, again, two possibilities. If Bank B's managers are incompetent, Bank A's managers are experienced. They will not diversify with Bank B, and Bank A's depositors will get the expected utility from the experienced undiversified return, *eu-e*. If Bank B's managers are experienced, Bank A's managers are incompetent, and Bank A gets expected utility *eu-n*.

For a given level of intensity of depositor risk aversion, if the average of *eu-i* and *eu-ie*, given the degree of diversification chosen by the experienced managers, exceeds the average of *eu-e* and *eu-n*, then there is no Nash equilibrium with double non-replacement. Moreover, if there is a Nash equilibrium with double replacement, then there cannot be a Nash equilibrium in which one bank replaces its managers and the other does not. Thus, the Nash equilibrium with double replacement is unique. Again, this is true in both versions of our baseline example.

Is the assumption that bank depositors live for only one period, while the government cares about depositors in both periods, essential for our results?

In this section of the appendix, we outline slightly more complicated assumptions under which there is a single set of bank depositors that live during and care about deposit returns earned during each period.

As before, we assume there is a set of depositors at the beginning of period 1, and that these depositors are divided into two equal-measure groups by location. Now, however, each depositor lives during both periods. Each period, each depositor may make his or her deposit at any of a continuum of banks in his location. In period 2, a depositor may choose to make his or her second deposit at the same bank she patronized in period 1, or at a different bank in his or her location. The loans originated by each bank in his or her location will yield the same return. In principle, however, different banks might make different diversification decisions.

A bank that does not receive deposits in period 1 closes down and is not available to accept deposits in period 2.

Consider the problem facing a representative depositor, in period 1, who is confronted by some banks whose managers announce that that they will diversify completely, and others who announce that they will limit their diversification. In our baseline example, complete diversification produces the most favorable return pattern for the depositor in period 1, while limited diversification of some sort produces the most favorable return pattern across the two periods. Because this depositor is not tied to the bank she chooses, in the next period, she has no incentive to choose a bank that limits diversification. The depositor is one of a continuum of depositors, and his or her individual decision does not influence the options available next period. The depositor will choose a bank that diversifies completely, expecting to be able to switch banks in the next period. If other depositors are concerned about the future implications of complete diversification, they will choose banks that limit diversification, giving them attractive banks to switch to.

In equilibrium, however, all the depositors will choose banks that diversify completely, and the only banks available to depositors in the next period will be banks that diversified completely in the previous period.

The government, however, can intervene to improve matters by restricting diversification. In this version of the model, what the government can do that the depositors cannot is impose coordination on the depositors. Without the government, if a group of depositors tries to get together in period 1 to support a bank that limits diversification, each individual in the group has an incentive to defect to a bank that offers a more favorable (completely diversified) return distribution this period, secure in the knowledge that she can "return to the fold" in the next period.

It is worth noting that this argument is reminiscent of a widely held view about a source of instability in our financial system. According to this view, banks have an incentive to chase "hot money," offering high interest rates to large, short-term depositors. Banks that do not do this cannot attract such depositors, which places them at a competitive disadvantage. However, the need to earn loan returns high enough to justify these high deposit rates forces the banks to take too much risk, endangering their future solvency. The large, short-term depositors are unconcerned about this situation, because they believe, correctly, that they can withdraw their deposits before the banks get into serious trouble. Ultimately, however, their actions help generate a financial crisis, the result of which is a severe recession during which high interest rates are no longer available to anyone. The government can intervene to solve the problem (or, at least, to reduce its severity) by regulating the banking system to prevent banks from taking excessive risks.

In our model, the loan return distribution is essentially exogenous, and the only way banks can differ from each other is in their degrees of diversification. However, according to the argument we have just developed, competitive pressure forces banks to choose a degree of diversification that is too "risky," in the sense of making the banking system vulnerable to severe financial crises, and making the economy more vulnerable to long, severe recessions. The government can ameliorate the problem by regulating the banking system to limit diversification.

Appendix B. The baseline numerical example

In Version 1 of the example, there are random shocks only to good base returns. Because $\varepsilon^b = 0$, in this version, we drop the subscript on ε^g when we describe it. In Version 2, there are also shocks to bad base returns, with $\varepsilon^b = \frac{1}{12}$. In both versions, as we have seen, we have $g = 1$, $\varepsilon^g = \frac{1}{3}$, $b = 1/2$, $q = \frac{5}{8}$, and $\theta_2 = \frac{1}{3}$. The probability structure is$p^e = \frac{3}{4}$, $p^i = \frac{1}{2}$, and $p^{me} = \frac{2}{3}$, so that $p^{ee} = \frac{1}{2}$, $p^{ei} = \frac{1}{4}$, and $p^{ii} = 0$.

Period 1: Return outcomes and implications, by diversification regime

No diversification [ND]

In this case ($\theta = 0$), each bank's depositors get the return on the loans originated by that bank.

The joint potential portfolio return outcomes$\{A, B\}$for period 1 (when the managers of both banks are experienced) are

$$\text{Version 1}: \left\{\begin{array}{llll} \left\{\frac{4}{3},\frac{4}{3}\right\}, & \left\{\frac{4}{3},\frac{2}{3}\right\}, & \left\{\frac{2}{3},\frac{4}{3}\right\}, & \left\{\frac{2}{3},\frac{2}{3}\right\} \\ \left\{\frac{4}{3},\frac{1}{2}\right\}, & \left\{\frac{2}{3},\frac{1}{2}\right\}, & & \\ \left\{\frac{1}{2},\frac{4}{3}\right\}, & \left\{\frac{1}{2},\frac{2}{3}\right\} & & \end{array}\right\} \qquad \text{Version 2}: \left\{\begin{array}{llll} \left\{\frac{4}{3},\frac{4}{3}\right\}, & \left\{\frac{4}{3},\frac{2}{3}\right\}, & \left\{\frac{2}{3},\frac{4}{3}\right\}, & \left\{\frac{2}{3},\frac{2}{3}\right\} \\ \left\{\frac{4}{3},\frac{7}{12}\right\}, & \left\{\frac{4}{3},\frac{5}{12}\right\}, & \left\{\frac{2}{3},\frac{7}{12}\right\}, & \left\{\frac{2}{3},\frac{5}{12}\right\} \\ \left\{\frac{7}{12},\frac{4}{3}\right\}, & \left\{\frac{7}{12},\frac{4}{3}\right\}, & \left\{\frac{5}{12},\frac{4}{3}\right\}, & \left\{\frac{5}{12},\frac{2}{3}\right\} \end{array}\right\}$$

The realized return outcomes are

$$\text{Version 1}: \left\{\begin{array}{llll} \left\{\frac{4}{3},\frac{4}{3}\right\}, & \left\{\frac{4}{3},\frac{2}{3}\right\}, & \left\{\frac{2}{3},\frac{4}{3}\right\}, & \left\{\frac{2}{3},\frac{2}{3}\right\} \\ \left\{\frac{4}{3},\frac{5}{8}\right\}, & \left\{\frac{2}{3},\frac{5}{8}\right\}, & & \\ \left\{\frac{5}{8},\frac{4}{3}\right\}, & \left\{\frac{5}{8},\frac{2}{3}\right\} & & \end{array}\right\} \qquad \text{Version 2}: \left\{\begin{array}{llll} \left\{\frac{4}{3},\frac{4}{3}\right\}, & \left\{\frac{4}{3},\frac{2}{3}\right\}, & \left\{\frac{2}{3},\frac{4}{3}\right\}, & \left\{\frac{2}{3},\frac{2}{3}\right\} \\ \left\{\frac{4}{3},\frac{5}{8}\right\}, & \left\{\frac{4}{3},\frac{5}{8}\right\}, & \left\{\frac{2}{3},\frac{5}{8}\right\}, & \left\{\frac{2}{3},\frac{5}{8}\right\} \\ \left\{\frac{5}{8},\frac{4}{3}\right\}, & \left\{\frac{5}{8},\frac{2}{3}\right\}, & \left\{\frac{5}{8},\frac{4}{3}\right\}, & \left\{\frac{5}{8},\frac{2}{3}\right\} \end{array}\right\}$$

because when the potential return outcome on the loans in a bank's portfolio is lower than q, the bank receives information that causes it to liquidate the portfolio. Note that, in Version 2, the realized joint return distribution also has only eight distinct outcomes.

For example, in Version 1, a mixed outcome favoring Bank B, with a low shock to the good base return, is potentially $\{A, B\} = \{b, g - \varepsilon\} = \{\frac{1}{2}, 1 - \frac{1}{3}\} = \{\frac{1}{2}, \frac{2}{3}\}$, but actually $\{A, B\} = \{q, g - \varepsilon\} = \{\frac{5}{8}, \frac{2}{3}\}$, because $b < q$, which is $\frac{1}{2} < \frac{5}{8}$. In Version 2, a mixed outcome of the same type, with a high shock to the low base return, is potentially $\{A, B\} = \{b + \varepsilon^b, g - \varepsilon^g\} = \{\frac{1}{2} + \frac{1}{12}, 1 - \frac{1}{3}\} = \{\frac{7}{12}, \frac{2}{3}\}$, but in reality $\{A, B\} = \{q, g - \varepsilon\} = \{\frac{5}{8}, \frac{2}{3}\}$, because $b + \varepsilon^b < q$, which is $\frac{1}{2} < \frac{5}{8}$.

When both banks have experienced managers, which is the situation in period 1, the eight distinct joint realized return outcomes are equally likely. In this case, the marginal realized return distribution for either bank is as follows:

$$\text{Versions 1 and 2}: \begin{array}{c} \text{outcome} \\ \text{probability} \end{array} \left\{\begin{array}{ccc} \frac{4}{3} & \frac{2}{3} & \frac{5}{8} \\ \frac{3}{8} & \frac{3}{8} & \frac{1}{4} \end{array}\right\}.$$

We call this return distribution *ee-nd*. Its expected utility is denoted as EU_s(*ee-nd*), where $s = 1, 2, 3$ represents the intensity of risk aversion, from lowest ($\gamma = 1$) to highest ($\gamma = 4$).

The probability that both banks will have experienced managers in period 2 is 1/2, the probability of a pure return outcome. If the joint return outcome in period 1 is mixed, it is clear, from the portfolio returns, which bank originated the bad loans: the bank whose return outcome is the liquidation return. Thus, the probability in period 2 that one bank will have experienced managers and the other will have inexperienced managers is also 1/2, and the probability that both banks will have inexperienced managers is 0.

Partial diversification [PD]

In this case ($\theta = \frac{1}{3}$), two-thirds of each bank's portfolio consists of loans the bank's managers originated, and one-third consists of the loans originated by the managers of the other bank.

The joint potential portfolio return outcomes $\{A, B\}$ for period 1 are

$$\text{Version 1}: \left\{\begin{array}{llll} \left\{\frac{4}{3},\frac{4}{3}\right\}, & \left\{\frac{10}{9},\frac{8}{9}\right\}, & \left\{\frac{8}{9},\frac{10}{9}\right\}, & \left\{\frac{2}{3},\frac{2}{3}\right\} \\ \left\{\frac{19}{18},\frac{7}{9}\right\}, & \left\{\frac{11}{18},\frac{5}{9}\right\}, & & \\ \left\{\frac{7}{9},\frac{19}{18}\right\}, & \left\{\frac{5}{9},\frac{11}{18}\right\} & & \end{array}\right\} \qquad \text{Version 2}: \left\{\begin{array}{llll} \left\{\frac{4}{3},\frac{4}{3}\right\}, & \left\{\frac{10}{9},\frac{8}{9}\right\}, & \left\{\frac{8}{9},\frac{10}{9}\right\}, & \left\{\frac{2}{3},\frac{2}{3}\right\} \\ \left\{\frac{13}{12},\frac{5}{6}\right\}, & \left\{\frac{37}{16},\frac{13}{18}\right\}, & \left\{\frac{23}{36},\frac{5}{8}\right\}, & \left\{\frac{7}{12},\frac{1}{2}\right\} \\ \left\{\frac{5}{6},\frac{13}{12}\right\}, & \left\{\frac{13}{18},\frac{37}{16}\right\}, & \left\{\frac{5}{8},\frac{23}{36}\right\}, & \left\{\frac{1}{2},\frac{7}{12}\right\} \end{array}\right\}$$

The realized return outcomes are

$$\text{Version 1}: \left\{\begin{array}{llll} \left\{\frac{4}{3},\frac{4}{3}\right\}, & \left\{\frac{10}{9},\frac{8}{9}\right\}, & \left\{\frac{8}{9},\frac{10}{9}\right\}, & \left\{\frac{2}{3},\frac{2}{3}\right\} \\ \left\{\frac{19}{18},\frac{7}{9}\right\}, & \left\{\frac{5}{8},\frac{5}{8}\right\}, & & \\ \left\{\frac{7}{9},\frac{19}{18}\right\}, & \left\{\frac{5}{8},\frac{5}{8}\right\} & & \end{array}\right\} \qquad \text{Version 2}: \left\{\begin{array}{llll} \left\{\frac{4}{3},\frac{4}{3}\right\}, & \left\{\frac{10}{9},\frac{8}{9}\right\}, & \left\{\frac{8}{9},\frac{10}{9}\right\}, & \left\{\frac{2}{3},\frac{2}{3}\right\} \\ \left\{\frac{13}{12},\frac{5}{6}\right\}, & \left\{\frac{37}{36},\frac{13}{18}\right\}, & \left\{\frac{23}{36},\frac{5}{8}\right\}, & \left\{\frac{5}{8},\frac{5}{8}\right\} \\ \left\{\frac{5}{6},\frac{13}{12}\right\}, & \left\{\frac{13}{18},\frac{37}{36}\right\}, & \left\{\frac{5}{8},\frac{23}{36}\right\}, & \left\{\frac{5}{8},\frac{5}{8}\right\} \end{array}\right\}$$

In this case, in Version 1, liquidation of both portfolios occurs whenever a mixed outcome features a low shock to the good base return. In Version 2, it occurs only when the low shock to the good base return is accompanied by a low shock to the bad base return.

For example, in Version 1, a mixed outcome favoring Bank A, with a high shock to the good base return, is

$$\{A, B\} = \{(1-\theta)(g+\varepsilon)+\theta\, b,\ \ (1-\theta)b+\theta(g+\varepsilon)\} = \left\{\tfrac{2}{3}\left(1+\tfrac{1}{3}\right)+\tfrac{1}{3}\left(\tfrac{1}{2}\right), \tfrac{2}{3}\left(\tfrac{1}{2}\right)+\tfrac{1}{3}\left(1+\tfrac{1}{3}\right)\right\} = \left\{\tfrac{19}{18}, \tfrac{7}{9}\right\}.$$

In Version 2, the same type of outcome, with a low shock to the bad base return, is

$$\begin{aligned}\{A, B\} &= \left\{(1-\theta)(g+\varepsilon^g)+\theta\left(b-\varepsilon^b\right),\ \ (1-\theta)\left(b-\varepsilon^b\right)+\theta(g+\varepsilon^g)\right\}.\\ &= \left\{\tfrac{2}{3}\left(1+\tfrac{1}{3}\right)+\tfrac{1}{3}\left(\tfrac{1}{2}-\tfrac{1}{12}\right), \tfrac{2}{3}\left(\tfrac{1}{2}-\tfrac{1}{12}\right)+\tfrac{1}{3}\left(1+\tfrac{1}{3}\right)\right\} = \left\{\tfrac{37}{36}, \tfrac{13}{18}\right\}\end{aligned}$$

In Version 1, when both banks have experienced managers, the eight outcomes are, again, equally likely. In Version 2, the four pure outcomes have a collective probability of 1/2 and are equally likely, and the eight mixed outcomes (though only seven are distinct) also have a collective probability of 1/2 and are also equally likely.

The realized marginal return distribution for either bank is

$$\text{Version 1}: \begin{array}{c}\text{outcome}\\ \text{probability}\end{array}\left\{\begin{array}{ccccccc}\frac{4}{3} & \frac{10}{9} & \frac{19}{18} & \frac{8}{9} & \frac{7}{9} & \frac{2}{3} & \frac{5}{8}\\ \frac{1}{8} & \frac{1}{8} & \frac{1}{8} & \frac{1}{8} & \frac{1}{8} & \frac{1}{8} & \frac{1}{4}\end{array}\right\}$$

$$\text{Version 2}: \begin{array}{c}\text{outcome}\\ \text{probability}\end{array}\left\{\begin{array}{cccccccccc}\frac{4}{3} & \frac{10}{9} & \frac{13}{12} & \frac{37}{36} & \frac{8}{9} & \frac{5}{6} & \frac{13}{18} & \frac{2}{3} & \frac{23}{26} & \frac{5}{8}\\ \frac{1}{8} & \frac{1}{8} & \frac{1}{16} & \frac{1}{16} & \frac{1}{8} & \frac{1}{16} & \frac{1}{16} & \frac{1}{8} & \frac{1}{16} & \frac{3}{16}\end{array}\right\}$$

We call these return distributions *ee-pd*. Their expected utility is denoted as EU_s(*ee-pd*), where $s = 1, 2, 3$ represents the intensity of risk aversion, from lowest ($\gamma = 1$) to highest ($\gamma = 4$).

Again, the probability that both banks will have experienced managers in period 2 is 1/2, the probability of a pure return outcome. If the joint return outcome in period 1 is mixed, and the two banks get different return outcomes, then the bank that originated the bad loans is the one with the lower portfolio return. Thus, in Version 1, the probability in period 2 that one bank will have experienced managers and the other will have inexperienced managers is 1/4. The probability that both banks will have inexperienced managers is also 1/4, which is the probability that both banks will liquidate their portfolios. Neither bank liquidates unless both do so. In Version 2, these probabilities are 3/8 and 1/8, respectively. For each bank, there is now a probability of 1/8 that it will fail, in period 1, as part of a systemic financial crisis, and a probability of 1/16 that it will be the only bank that fails.

Complete diversification [CD]

In this case ($\theta = \frac{1}{2}$), each bank's portfolio is equally divided between loans the bank's managers originated and loans originated by the managers of the other bank.

The joint potential portfolio return outcomes {*A, B*} for period 1 are

$$\text{Version 1}: \left\{\begin{array}{l}\left\{\frac{4}{3},\frac{4}{3}\right\},\ \{1,1\},\ \{1,1\},\ \left\{\frac{2}{3},\frac{2}{3}\right\}\\ \left\{\frac{11}{12},\frac{11}{12}\right\},\ \left\{\frac{7}{12},\frac{7}{12}\right\},\\ \left\{\frac{7}{12},\frac{7}{12}\right\},\ \left\{\frac{11}{12},\frac{11}{12}\right\}\end{array}\right\} \qquad \text{Version 2}: \left\{\begin{array}{l}\left\{\frac{4}{3},\frac{4}{3}\right\},\ \{1,1\},\ \{1,1\},\ \left\{\frac{2}{3},\frac{2}{3}\right\}\\ \left\{\frac{23}{24},\frac{23}{24}\right\},\ \left\{\frac{7}{8},\frac{7}{8}\right\},\ \left\{\frac{5}{8},\frac{5}{8}\right\},\ \left\{\frac{13}{24},\frac{13}{24}\right\}\\ \left\{\frac{23}{24},\frac{23}{24}\right\},\ \left\{\frac{5}{8},\frac{5}{8}\right\},\ \left\{\frac{7}{8},\frac{7}{8}\right\},\ \left\{\frac{13}{24},\frac{13}{24}\right\}\end{array}\right\}$$

The realized return outcomes are

$$\text{Version 1}: \left\{\begin{array}{l}\left\{\frac{4}{3},\frac{4}{3}\right\},\ \{1,1\},\ \{1,1\},\ \left\{\frac{2}{3},\frac{2}{3}\right\}\\ \left\{\frac{11}{12},\frac{11}{12}\right\},\ \left\{\frac{5}{8},\frac{5}{8}\right\},\\ \left\{\frac{5}{8},\frac{5}{8}\right\},\ \left\{\frac{11}{12},\frac{11}{12}\right\}\end{array}\right\} \qquad \text{Version 2}: \left\{\begin{array}{l}\left\{\frac{4}{3},\frac{4}{3}\right\},\ \{1,1\},\ \{1,1\},\ \left\{\frac{2}{3},\frac{2}{3}\right\}\\ \left\{\frac{23}{24},\frac{23}{24}\right\},\ \left\{\frac{7}{8},\frac{7}{8}\right\},\ \left\{\frac{5}{8},\frac{5}{8}\right\},\ \left\{\frac{5}{8},\frac{5}{8}\right\}\\ \left\{\frac{23}{24},\frac{23}{24}\right\},\ \left\{\frac{5}{8},\frac{5}{8}\right\},\ \left\{\frac{7}{8},\frac{7}{8}\right\},\ \left\{\frac{5}{8},\frac{5}{8}\right\}\end{array}\right\}$$

In both versions, liquidation of both portfolios, or an equivalent joint return outcome, occurs whenever a mixed outcome features a low shock to the good base return.

For example, in both versions, a pure outcome, with a high shock to Bank A's base return and a low shock to Bank B's, is

$$\begin{aligned}\{A, B\} &= \{(1-\theta)(g+\varepsilon)+\theta\,(g-\varepsilon),\ \ (1-\theta)(g-\varepsilon)+\theta\,(g+\varepsilon)\}\\ &= \left\{\tfrac{1}{2}\left(1+\tfrac{1}{3}\right)+\tfrac{1}{2}\left(1-\tfrac{1}{3}\right),\ \tfrac{1}{2}\left(1-\tfrac{1}{3}\right)+\tfrac{1}{2}\left(1+\tfrac{1}{3}\right)\right\} = \{1,1\}.\end{aligned}$$

When both banks have experienced managers, in Version 1, the eight joint return outcomes (although only six are distinct) are again equally likely. Furthermore, again, in Version 2, the four mixed outcomes (only three of which are distinct) have a collective probability of 1/2 and are equally likely, and the eight pure outcomes (only three of which are distinct) also have collective probability of 1/2 and are equally likely.

The realized marginal return distribution for either bank is

$$\text{Version 1}: \begin{array}{c}\text{outcome}\\ \text{probability}\end{array}\left\{\begin{array}{ccccc}\frac{4}{3} & 1 & \frac{11}{12} & \frac{2}{3} & \frac{5}{8}\\ \frac{1}{8} & \frac{1}{4} & \frac{1}{4} & \frac{1}{8} & \frac{1}{4}\end{array}\right\} \qquad \text{Version 2}: \left\{\begin{array}{cccccc}\frac{4}{3} & 1 & \frac{23}{24} & \frac{7}{8} & \frac{2}{3} & \frac{5}{8}\\ \frac{1}{8} & \frac{1}{4} & \frac{1}{8} & \frac{1}{8} & \frac{1}{8} & \frac{1}{4}\end{array}\right\}$$

We call these return distributions *ee-cd*. Their expected utility is denoted as EU_s(*ee-cd*), where $s = 1, 2, 3$ represents the intensity of risk aversion, from lowest ($\gamma = 1$) to highest ($\gamma = 4$).

As usual, the probability that both banks will have experienced managers in period 2 is 1/2, the probability of a pure return outcome. However, the probability that both banks will have inexperienced managers is also 1/2, so that the probability that one bank will have experienced managers and the other will have inexperienced managers is 0. Because the two banks always have identical portfolio returns, if there is a mixed return outcome, then it is never possible to identify the bank whose mangers are at fault. It follows that, in both versions, neither bank liquidates unless both do so.

Period 2: Portfolio return distributions by experience of managers

Experienced–experienced

When the managers of both banks are experienced, the return distributions are identical to those from period 1, when the same situation holds. Because there is no rationale for government intervention in period 2, we assume the two banks choose the diversification regime that yields the highest expected utility for their depositors. In our baseline example, this regime turns out to be CD, regardless of the version of the example or the depositors' intensity of risk aversion. Thus, the return distribution is *ee-cd,* and its expected utility is EU_s(*ee-cd*), $s = 1, 2, 3$.

Experienced–inexperienced, and vice versa

When one bank has experienced managers, we assume that the bank with experienced managers (Bank A, here) chooses the degree of diversification, because this bank has less to gain from diversification. The joint return outcomes are the same as for period 1, but their probabilities are different. The four pure outcomes have a collective probability of 1/4. The two (Version 1) or four (Version 2) mixed outcomes favoring Bank A have a collective probability of 1/2, while the two or four mixed outcomes favoring Bank B have a collective probability of 1/4.

The marginal realized return distributions are as follows:

Bank A (experienced managers)

$$\text{ND}: \text{ Versions 1 and 2}: \begin{matrix}\text{outcome}\\ \text{probability}\end{matrix} \left\{\begin{matrix} \frac{4}{3} & \frac{2}{3} & \frac{5}{8} \\ \frac{3}{8} & \frac{3}{8} & \frac{1}{4} \end{matrix}\right\}$$

$$\text{PD}: \text{ Version 1}: \begin{matrix}\text{outcome}\\ \text{probability}\end{matrix} \left\{\begin{matrix} \frac{4}{3} & \frac{10}{9} & \frac{19}{18} & \frac{8}{9} & \frac{7}{9} & \frac{2}{3} & \frac{5}{8} \\ \frac{1}{16} & \frac{1}{16} & \frac{1}{4} & \frac{1}{16} & \frac{1}{8} & \frac{1}{16} & \frac{3}{8} \end{matrix}\right\},$$

$$\text{Version 2}: \begin{matrix}\text{outcome}\\ \text{probability}\end{matrix} \left\{\begin{matrix} \frac{4}{3} & \frac{10}{9} & \frac{13}{12} & \frac{37}{36} & \frac{8}{9} & \frac{5}{6} & \frac{13}{18} & \frac{2}{3} & \frac{23}{26} & \frac{5}{8} \\ \frac{1}{16} & \frac{1}{16} & \frac{1}{8} & \frac{1}{8} & \frac{1}{16} & \frac{1}{16} & \frac{1}{16} & \frac{1}{16} & \frac{1}{8} & \frac{1}{4} \end{matrix}\right\}$$

$$\text{CD}: \text{ Version 1}: \begin{matrix}\text{outcome}\\ \text{probability}\end{matrix} \left\{\begin{matrix} \frac{4}{3} & 1 & \frac{11}{12} & \frac{2}{3} & \frac{5}{8} \\ \frac{1}{16} & \frac{1}{8} & \frac{3}{8} & \frac{1}{16} & \frac{3}{8} \end{matrix}\right\},$$

$$\text{Version 2}: \begin{matrix}\text{outcome}\\ \text{probability}\end{matrix} \left\{\begin{matrix} \frac{4}{3} & 1 & \frac{23}{24} & \frac{7}{8} & \frac{2}{3} & \frac{5}{8} \\ \frac{1}{16} & \frac{1}{8} & \frac{3}{16} & \frac{3}{16} & \frac{1}{16} & \frac{3}{8} \end{matrix}\right\}$$

We call these return distributions *ei-nd, ei-pd,* and *ei-cd*, respectively, and their expected utilities are EU_s(*ei-nd*), EU_s(*ei-pd*), and EU_s(*ei-cd*), respectively, $s = 1, 2, 3$.

Bank B (inexperienced managers)

$$\text{ND}: \text{ Versions 1 and 2}: \begin{matrix}\text{outcome}\\ \text{probability}\end{matrix} \left\{\begin{matrix} \frac{4}{3} & \frac{2}{3} & \frac{5}{8} \\ \frac{1}{4} & \frac{1}{4} & \frac{1}{2} \end{matrix}\right\},$$

$$\text{PD}: \text{ Version 1}: \begin{matrix}\text{outcome}\\ \text{probability}\end{matrix} \left\{\begin{matrix} \frac{4}{3} & \frac{10}{9} & \frac{19}{18} & \frac{8}{9} & \frac{7}{9} & \frac{2}{3} & \frac{5}{8} \\ \frac{1}{16} & \frac{1}{16} & \frac{1}{8} & \frac{1}{16} & \frac{1}{4} & \frac{1}{16} & \frac{3}{8} \end{matrix}\right\}$$

$$\text{Version 2}: \begin{matrix}\text{outcome}\\ \text{probability}\end{matrix} \left\{\begin{matrix} \frac{4}{3} & \frac{10}{9} & \frac{13}{12} & \frac{37}{36} & \frac{8}{9} & \frac{5}{6} & \frac{13}{18} & \frac{2}{3} & \frac{23}{26} & \frac{5}{8} \\ \frac{1}{16} & \frac{1}{16} & \frac{1}{16} & \frac{1}{16} & \frac{1}{16} & \frac{1}{8} & \frac{1}{8} & \frac{1}{16} & \frac{1}{16} & \frac{5}{16} \end{matrix}\right\}$$

$$\text{CD}: \text{ Version 1}: \begin{matrix}\text{outcome}\\ \text{probability}\end{matrix} \left\{\begin{matrix} \frac{4}{3} & 1 & \frac{11}{12} & \frac{2}{3} & \frac{5}{8} \\ \frac{1}{16} & \frac{1}{8} & \frac{3}{8} & \frac{1}{16} & \frac{3}{8} \end{matrix}\right\}$$

$$\begin{matrix}\text{outcome}\\ \text{probability}\end{matrix} \left\{\begin{matrix} \frac{4}{3} & 1 & \frac{23}{24} & \frac{7}{8} & \frac{2}{3} & \frac{5}{8} \\ \frac{1}{16} & \frac{1}{8} & \frac{3}{16} & \frac{3}{16} & \frac{1}{16} & \frac{3}{8} \end{matrix}\right\}$$

We call these return distributions *ie-nd, ie-pd,* and *ie-cd*, respectively, and their expected utilities are EU_s(*ie-nd*), EU_s(*ie-pd*), and EU_s(*ie-cd*), respectively, $s = 1, 2, 3$.

Inexperienced–inexperienced

When both banks have inexperienced managers, the four pure outcomes have a collective probability of 0 and, thus, individual probabilities of 0. The two (or four) mixed outcomes favoring Bank A have a collective probability of 1/2, as do the two (or four) mixed outcomes favoring Bank B.

The marginal realized return distributions are as follows:

$$\text{ND}: \text{ Versions 1 and 2}: \begin{matrix}\text{outcome}\\ \text{probability}\end{matrix}\left\{\begin{matrix}\frac{4}{3} & \frac{2}{3} & \frac{5}{8}\\ \frac{1}{4} & \frac{1}{4} & \frac{1}{2}\end{matrix}\right\}$$

$$\text{PD}: \text{ Version 1}: \begin{matrix}\text{outcome}\\ \text{probability}\end{matrix}\left\{\begin{matrix}\frac{19}{18} & \frac{7}{9} & \frac{5}{8}\\ \frac{1}{4} & \frac{1}{4} & \frac{1}{2}\end{matrix}\right\} \quad \text{Version 2}: \begin{matrix}\text{outcome}\\ \text{probability}\end{matrix}\left\{\begin{matrix}\frac{13}{12} & \frac{37}{36} & \frac{5}{6} & \frac{13}{18} & \frac{23}{36} & \frac{5}{8}\\ \frac{1}{8} & \frac{1}{8} & \frac{1}{8} & \frac{1}{8} & \frac{1}{8} & \frac{3}{8}\end{matrix}\right\}$$

$$\text{CD}: \text{ Version 1}: \begin{matrix}\text{outcome}\\ \text{probability}\end{matrix}\left\{\begin{matrix}\frac{11}{12} & \frac{5}{8}\\ \frac{1}{2} & \frac{1}{2}\end{matrix}\right\} \quad \text{Version 2}: \begin{matrix}\text{outcome}\\ \text{probability}\end{matrix}\left\{\begin{matrix}\frac{23}{24} & \frac{7}{8} & \frac{5}{8}\\ \frac{1}{4} & \frac{1}{4} & \frac{1}{2}\end{matrix}\right\}$$

We call these return distributions *ii-nd, ii-pd,* and *ii-cd*, respectively, and their expected utilities are EU_s(*ii-nd*), EU_s(*ii-pd*), and EU_s(*ii-cd*), respectively, $s = 1, 2, 3$.

Period 2: Diversification decisions

As we have seen, when the managers of both banks are experienced, they choose the CD diversification regime in period 2, regardless of their intensity of risk aversion. They obtain the expected utility EU_s(*ee-cd*), $s = 1, 2, 3$.

When the managers of one bank are experienced (Bank A) and the managers of the other bank (Bank B) are inexperienced, the diversification regime the Bank A managers choose depends on their intensity of risk aversion. If it is weak or moderate, they choose not to diversify, as the decrease in the expected return outweighs the benefit from risk spreading. If it is strong, they choose to diversify completely (CD) in Version 1 of the baseline example or partially (PD), in Version 2.

Thus, in the case of weak or moderate depositor risk aversion, the depositors of the bank with experienced managers get return distribution *ei-nd* and expected utility EU_s(*ei-nd*), $s = 1$ or 2. In the case of strong risk aversion, they get distribution *ei-cd* and expected utility EU_3(*ei-cd*), in the simple version of the model, or *ei-pd* and expected utility EU_3(*ei-pd*). For the depositors of the bank with experienced managers, we simply replace *ei* with *ie*. When we calculate the ex-ante expected utility of a period-2 depositor, we must average across the two relevant expected utilities, treating the depositor as unsure of which bank she will be associated with.

When the managers of both banks are inexperienced, if their depositors are weakly risk averse, they choose not to diversify, because the potential losses from inefficient liquidation outweigh the benefits from risk spreading. (These losses are magnified because every return outcome includes a bad base return.) The depositors get return distribution *ii-nd* and expected utility EU_1(*ii-nd*). Otherwise, they choose to diversify completely, so that their depositors get return distribution *ii-cd* and expected utility EU_s(*ii-cd*), $s = 2$ or 3.

It remains to verify that, in the case where there is a mixed joint return outcome in period 1, and the identity of the bank whose managers made the bad loans (and are thus incompetent) cannot be determined, there is a unique symmetric pure-strategies Nash equilibrium in which both banks replace their managers.

Period 2: The manager replacement decision when the identity of the "bad" managers is unknown

As we have seen, to confirm that there is a pure-strategies Nash equilibrium in which the managers of both banks are replaced, we must start by calculating the expected utility received by a bank with inexperienced managers, when the managers of the other bank are also inexperienced. This value is EU_1(*ii-nd*) or EU_s(*ii-cd*), $s = 2$ or 3. Next, we calculate the expected utility received by a bank with incompetent managers, which we will denote as $EU_s(n)$, $s = 1, 2$ or 3: it is simply the expected utility of a return of q $(\frac{5}{8})$ received with certainty. Finally, we calculate the expected utility received by a bank with experienced managers when the managers of the other bank are inexperienced, which is EU_s(*ei-nd*), $s = 1$ or 2, or EU_3(*ei-cd*).

If $EU_1(ii{-}nd) \geq \frac{1}{2}\{EU_1(n) + EU_1(ei{-}nd)\}$, then we have our Nash equilibrium when $s = 1$ (weak risk aversion).

If $EU_2(ii{-}cd) \geq \frac{1}{2}\{EU_2(n) + EU_2(ei{-}nd)\}$, then we have our Nash equilibrium when $s = 2$ (moderate risk aversion).

If $EU_3(ii{-}cd) \geq \frac{1}{2}\{EU_3(n) + EU_3(ei{-}cd)\}$, in Version 1 of the baseline example, or $EU_3(ii{-}cd) \geq \frac{1}{2}\{EU_3(n) + EU_3(ei{-}pd)\}$, in Version 2, then then we have our Nash equilibrium when $s = 3$ (strong risk aversion).

It turns out that all three of these inequalities hold (strictly). Thus, in our baseline examples, there is always a Nash equilibrium in which the managers of both banks are replaced, regardless of depositors' intensity of risk aversion.

To prove that this pure-strategies Nash equilibrium is unique, we need to show that if one bank does not replace its managers, then it is optimal for the other bank to replace its managers. As we have seen, if Bank B does not replace its managers, but Bank A does (meaning that its managers are inexperienced), then there are two possibilities. Bank B's managers may be incompetent, in which case Bank A's depositors get the inexperienced–undiversified return, with expected utility EU_s(*ii-nd*), $s = 1, 2$ or 3, or, Bank B's managers may be experienced, in which case Bank A's depositors get the inexperienced–experienced return, with expected utility EU_s(*ie-nd*), $s = 1$ or 2, or EU_3(*ie-cd*) (Version 1), or EU_3(*ie-pd*) (Version 2).

If Bank A does not replace its managers, there are again two possibilities. Bank B's managers may be incompetent, in which case Bank A's managers are experienced. Its depositors will get the experienced–undiversified return distribution, with expected utility EU_s(*ee-nd*), $s = 1, 2$ or 3. Alternatively, Bank B's managers may be experienced, in which case Bank A's are incompetent, and its depositors get expected utility $EU_s(n)$, $s = 1, 2$ or 3.

Thus, if $\frac{1}{2}\{EU_s(ii{-}nd) + EU_s(ie{-}nd)\} \geq \frac{1}{2}\{EU_s(ee{-}nd) + EU_s(n)\}$, then there is no Nash equilibrium in which both banks do not replace their managers, $s = 1$ or 2.

If $\frac{1}{2}\{EU_3(ii-nd)+EU_3(ie-cd)\} \geq \frac{1}{2}\{EU_3(ee-nd)+EU_3(n)\}$ (Version 1), or $\frac{1}{2}\{EU_3(ii-nd)+EU_3(ie-pd)\} \geq \frac{1}{2}\{EU_3(ee-nd)+EU_3(n)\}$ (Version 2), then the same is true for $s = 3$.

Again, all these inequalities hold, strictly, so in our baseline example, there is no Nash equilibrium in which both sets of managers are retained. It follows, as we have seen, that the equilibrium in which both sets of managers are replaced is unique.

The unregulated equilibrium and the welfare case for government regulation

Is there a rationale for government intervention to prohibit or restrict interconnectedness in the first period?

We begin with the question of what the banks will do, in both periods, if they are not regulated.

In period 1, they will choose CD, regardless of their depositors' intensity of risk aversion. In period 2, there is a probability of 1/2 that both banks have experienced managers, so that the situation from period 1 recurs, and the banks again choose complete diversification.

There is also a probability of 1/2 that the managers of both banks are inexperienced. In this case, they do not diversify at all if they are weakly risk averse, and they diversify completely if they are moderately or strongly risk averse.

Again, the government's welfare criterion is the average ex-ante expected utility of a depositor, across the two periods, assuming that, in each period, the depositor is equally likely to be a customer of either bank. Thus, the value of this criterion is

$$\frac{1}{2}\left\{EU_1(ee-cd)+\frac{EU_1(ee-cd)+EU_1(ii-nd)}{2}\right\},\ \text{for } s=1,\ \text{or}$$

$$\frac{1}{2}\left\{EU_s(ee-cd)+\frac{EU_s(ee-cd)+EU_s(ii-cd)}{2}\right\},\ \text{for } s=2 \text{ or } 3.$$

To determine the government's optimal regulation decision, we also need to know the value of this welfare criterion if the banks choose ND or PD in period 1, perhaps because this choice is imposed on them, or perhaps as the best of a set of restricted choices.

If they choose ND in period 1, there is again a probability of 1/2 that the return outcome will be pure, that they will both have experienced managers in period 2, and that they will choose CD. There is also a probability of 1/2 that the return outcome will be mixed, in which case one of the two banks will have experienced managers and the other will have inexperienced managers.

Thus, the value of the government's welfare criterion is

$$\frac{1}{2}\left\{EU_s(ee-nd)+\frac{EU_s(ee-cd)+\frac{1}{2}\left[EU_s(ei-nd)+EU_s(ie-nd)\right]}{2}\right\}, s=1 \text{ or } 2,\ \text{or}$$

$$\frac{1}{2}\left\{EU_3(ee-nd)+\frac{EU_3(ee-cd)+\frac{1}{2}\left[EU_3(ei-cd)+EU_i(ie-cd)\right]}{2}\right\} \text{(Version 1)}$$

$$\frac{1}{2}\left\{EU_3(ee-nd)+\frac{EU_3(ee-cd)+\frac{1}{2}\left[EU_3(ei-pd)+EU_i(ie-pd)\right]}{2}\right\} \text{(Version 2)},\ s=3.$$

If they choose PD, then in Version 1 of our baseline example, there is a probability of 1/2 of a pure outcome that produces two sets of experienced managers, a probability of 1/4 of a mixed outcome that produces banks whose managers have different levels of experience, and a probability of 1/4 of a mixed outcome that produces two sets of inexperienced managers. In Version 2, however, the probability that the banks will have managers with different levels of experience is 3/8, and the probability that both banks will have inexperienced managers is 1/8.

Thus, in Version 1, the value of the government's welfare criterion is

$$\frac{1}{2}\left\{EU_1(ee-pd)+\left[\frac{1}{2}EU_1(ee-cd)+\frac{1}{4}\left\{\frac{EU_1(ei-nd)+EU_1(ie-nd)}{2}\right\}+\frac{1}{4}EU_1(ii-nd)\right]\right\},\ s=1,$$

$$\frac{1}{2}\left\{EU_2(ee-pd)+\left[\frac{1}{2}EU_2(ee-cd)+\frac{1}{4}\left\{\frac{EU_2(ei-nd)+EU_2(ie-nd)}{2}\right\}+\frac{1}{4}EU_2(ii-cd)\right]\right\},\ s=2,$$

$$\frac{1}{2}\left\{EU_3(ee-pd)+\left[\frac{1}{2}EU_3(ee-cd)+\frac{1}{4}\left\{\frac{EU_3(ei-cd)+EU_3(ie-cd)}{2}\right\}+\frac{1}{4}EU_3(ii-cd)\right]\right\},\ s=3,$$

while in Version 2, it is

$$\frac{1}{2}\left\{EU_1(ee-pd)+\left[\frac{1}{2}EU_1(ee-cd)+\frac{3}{8}\left\{\frac{EU_1(ei-nd)+EU_1(ie-nd)}{2}\right\}+\frac{1}{8}EU_1(ii-nd)\right]\right\},\ s=1,$$

$$\frac{1}{2}\left\{EU_2(ee-pd)+\left[\frac{1}{2}EU_2(ee-cd)+\frac{3}{8}\left\{\frac{EU_2(ei-nd)+EU_2(ie-nd)}{2}\right\}+\frac{1}{8}EU_2(ii-cd)\right]\right\},\ s=2,$$

$$\frac{1}{2}\left\{ EU_3(ee{-}pd) + \left[\frac{1}{2}EU_3(ee{-}cd) + \frac{3}{8}\left\{ \frac{EU_3(ei{-}pd) + EU_3(ie{-}pd)}{2} \right\} + \frac{1}{8}EU_3(ii{-}cd)\right]\right\},\ s = 3.$$

It turns out that, if the depositors are weakly risk averse, ND in period 1 produces the highest value for the government's welfare criterion, followed by PD and then CD. However, CD is the banks' preferred choice in period 1, followed by PD and then ND. Therefore, the government must rule out both CD and PD, imposing ND, which is to say, prohibiting diversification.

If the depositors are moderately or strongly risk averse, PD in period 1 produces the highest value for the government's welfare criterion, followed by CD and then ND. Again, however, the banks prefer CD in period 1, followed by PD and then ND. Therefore, the government must prohibit CD in period 1, causing to banks to choose PD. That is, the government limits but does not prohibit diversification.

References

Allen, Franklin, Gale, Douglas, 2000. Financial contagion. J. Political Econ. 108 (1), 1–33.

Batiz-Zuk, Enrique, López-Gallo, Fabrizio, Martínez-Jaramillo, Serafín, Solórzano-Margain, Juan Pablo, 2016. Calibrating limits for large interbank exposure from a system-wide perspective. J. Financ. Stab. 27, 198–216.

Bernanke, Benjamin. 2007. "The financial accelerator and the credit channel." Address at the Federal Reserve Bank of Atlanta's Conference on the Credit Channel of Monetary Policy in the 21st Century. Board of Governors of the Federal Reserve System, June.

Bimpikis, Kostas and Alireza Tahbaz-Salehiz. 2013. "Inefficient diversification." Columbia Business School Research Paper no. 13-1, January.

Boissay, Frederic, Collard, Fabrice, Smets, Frank, 2016. Booms and banking crises. J. Political Econ. 124 (2 (April)), 489–538.

Calomiris, Charles W., Kahn, Charles M., 1991. The role of demandable debt in structuring optimal banking arrangements. Am. Econ. Rev. 81 (3 (February)), 497–513.

Diamond, Douglas W., Dybvig, Philip H., 1983. Bank runs, deposit insurance, and liquidity. J. Political Econ. 91 (3 (June)), 401–419.

Espinosa-Vega, Marco A., Solé, Juan, 2011. Cross-Border Surveillance: A Network Perspective. Journal of Financial Economic Policy 3 (3), 182–205.

Gambacorta, Leonardo, van Rixtel, Adrian, 2013. Structural Bank Regulation Initiatives: Approaches and Implications. Bancaria 6 (January), 14–27.

Greenwood, Jeremy, Jovanovic, Boyan, 1990. Financial development, growth, and the distribution of income. J. Political Econ. 98 (5), 1076–1107.

Ibragimov, Rustam, Jaffee, Dwight, Walden, Johan, 2011. Diversification disasters. J. Financ. Econ. 99 (September), 333–348.

Jordá, Oscar, Moritz Schularick and Alan M. Taylor. 2014. "The great mortgaging: housing finance, crises, and business cycles." *CEPR Discussion Papers* DP10161 (September).

Kannan, Prakash, Scott, Alasdair, Terrones, Marco E, 2009. From recession to recovery: how soon and how strong? World Economic Outlook. International Monetary Fund April.

The Financial Crisis Inquiry Commission, 2011. The financial crisis inquiry report. National Commission on the Causes of the Financial and Economic Crisis of the United States. U.S. Government Printing Office February.

Reinhart, Carmen M., Rogoff, Kenneth S., 2009. The aftermath of financial crises. Am. Econ. Rev. 99 (2 (May)), 466–472.

Roukny, Tarik, Battiston, Stefano, Stiglitz, Joseph E., 2018. Interconnectedness as a source of uncertainty in systemic risk. J. Financ. Stab. 35, 93–106.

Wagner, Wolf, 2010. Diversification at financial institutions and systemic crises. J. Financ. Intermed. 19 (July), 373–386.

Wagner, Wolf, 2011. Systemic liquidation risk and the diversity-diversification trade-off. J. Financ. 4 (August), 1141–1175 LXVI.

Wallace, Neil, 1988. Another attempt to explain an illiquid banking system: the diamond and dybvig model with sequential service taken seriously. Federal Reserve Bank of Minneapolis Q. Rev. 12 (4 (Fall)), 3–16.