Housing, Mortgage Recourse, and Financial Fragility*

Jiahong Gao Robert R. Reed

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Abstract

During the Global Financial Crisis, there were increasing concerns about the effects of mortgage market activity on the stability of the financial system. Given the important role of banks for extending mortgage funding, how does the legal environment regarding mortgage default impact mortgage market activity and thus financial fragility? What is the optimal degree of mortgage recourse? We study these questions in a version of Diamond and Dybvig (1983) where banks with limited commitment issue mortgages through maturity transformation and can raise liquidity by selling loans on secondary markets. In particular, we demonstrate that if borrowers incur lower costs in the event of foreclosure, intermediaries will generally be compensated for default risk with higher interest rates on mortgages. Interestingly, the banking system is not necessarily less stable at lower penalties for default. In addition, regardless of the probability of a financial crisis, relatively high protections for borrowers are likely to increase expected utility. In general, however, neither a no-recourse policy nor a full-recourse regime maximizes social welfare.

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*We thank seminar participants at the University of Mississippi for their helpful comments. Jiahong Gao: Wenlan School of Business, Zhongnan University of Economics and Law. E-mail address: jiahong.gao@zuel.edu.cn; Tel.: +86 13063038299. Please address correspondence to Robert R. Reed: Department of Economics, Finance and Legal Studies, University of Alabama. E-mail address: rreed@cba.ua.edu; Tel.: +1 (205) 348-8667.

1 Introduction

In recent years, real-estate related assets have been one of the largest components of the balance sheets of depository institutions in the United States.[1] During periods of financial distress, however, housing market activity may slump and defaults on mortgages may occur. Given the important role of banks for extending residential mortgages through maturity transformation, which may leave themselves fragile, it is important to understand how mortgage market conditions affect the stability of the financial system. In particular, in the midst of the Global Financial Crisis, there were increasing concerns raised about the legal landscape over mortgage default. For example, as argued by Feldstein (2008), one critical reason why falling house prices triggered record numbers of defaults on mortgages in the United States was due to low costs of default as a result of "no-recourse" mortgages.[2] Further, Ghent and Kudlyak (2011) find evidence that borrowers are more likely to strategically default in non-recourse states, especially for homes appraised at relatively high values. Similarly, Demiroglu et al. (2014) observe that homeowners with negative equity are more likely to default in states with borrower-friendly foreclosure laws. Thus, if intermediaries cannot pursue a deficiency judgment in the event of default, non-recourse provisions may transfer risk from borrowers to risk-averse depositors. In this vein, by impacting the degree of liquidity transformation performed by banks that respond to idiosyncratic short-term withdrawals, the legal environment regarding mortgage default affects intermediaries' exposure to liquidity risk and therefore financial stability.

The objective of this paper is to examine the implications of the legal landscape over mortgage default for mortgage market activity and financial fragility. To this end, it is important to develop a rigorous model that is capable of demonstrating the incentives of different groups of mortgage market participants. Moreover, as liquidity risk in the most recent crisis has drawn a significant amount of attention, we follow a tradition in the microeconomics of financial intermediation of Diamond and Dybvig (1983) with the friction of limited commitment as in Ennis and Keister (2009). In this setting, banks can be susceptible to run behavior, which occurs with a positive probability, and are unable to commit to a course of actions but issue payments to withdrawing consumers optimally given the situation at hand. In contrast to previous work, however, we incorporate housing and mortgage markets as in Reed et al. (2018) so that the return to bank lending is endogenous.

[1] For example, based upon data on assets and liabilities of commercial banks in the United States as of July 13, 2022, real-estate related assets are among the largest components of banks' balance sheets, which account for 35.08%. Data source: https://www.federalreserve.gov/releases/h8/current/default.htm.

[2] Specifically, recourse mortgages are a type of secured loan that allows the lender to pursue a deficiency judgement against a defaulter. In the case of non-recourse mortgages, a lender can only seize the real estate property but cannot go after the borrower's other assets in the event of foreclosure. Currently, there are thirteen "non-recourse" states in the U.S., including Alaska, Arizona, California, Connecticut, Hawaii, Idaho, Minnesota, Nevada, North Carolina, North Dakota, Texas, Utah, and Washington.

Importantly, this novel approach in the context of bank runs allows us to demonstrate how the vulnerability of intermediaries to a panic depends on mortgage market conditions – especially the legal environment regarding mortgage default which attracted so much interest during the Global Financial Crisis. In addition, we augment the model to include secondary markets where banks can raise liquidity by selling loans to outside investors at prices determined by cash-in-the-market pricing as in Allen and Gale (1998).

Prior to outlining the details of the results, we begin by highlighting some important features of the modeling framework. In particular, in our setup, there are two different groups of participants in the mortgage market. To be specific, to extend loans to potential homebuyers who seek access to mortgages in order to purchase homes, financial intermediaries attract funds by issuing short-term liabilities to risk-averse depositors. Interestingly, our model allows for the potential for strategic default on loans by mortgage borrowers who are subject to idiosyncratic shocks to the value from homeownership. That is, if homebuyers experience adverse housing shocks, it might be better for them to simply walk away from their mortgage obligations. As mortgage losses are ultimately borne by risk-averse depositors should defaults occur, protections for borrowers may disrupt the ability of intermediaries to perform their important risk-pooling functions.

We now turn to address the primary questions of interest. To begin, how do mortgage recourse provisions affect mortgage market activity? Our model indicates that if borrowers incur lower costs in the event of foreclosure, intermediaries will generally be compensated for default risk with higher interest rates on mortgages. Notably, such an increase in the loan return in compensation arises when the probability of a run is low and the same occurs if crises are more likely to emerge as long as the equilibrium mortgage rate is not arbitrarily high. Given that intermediaries obtain higher mortgage rates at lower penalties for default, how is the degree of financial stability affected by protections for borrowers? We show by examples that regardless of the bank's portfolio choice, there exhibits a non-linear relationship between financial fragility and the degree of mortgage recourse. More importantly, the banking system is not necessarily less stable at lower penalties for default. In particular, it is possible that the scope for run equilibria where borrowers have full insurance against default is exactly the same as that should full recourse provisions be in place.

To deepen our understanding of the role of the legal environment over mortgage default, we turn to examine the welfare implications that arise from our model along with optimal recourse policy. Interestingly, our numerical simulations indicate that irrespective of the probability of a financial crisis, relatively high protections for borrowers are likely to maxmize the sum of all agents' expected utilities. In a less crisis-prone economy, for example, imposing sufficiently high default penalties tends to lower welfare as banks become more conservative in issuing liabilities due to low interest rates and less loan sales. In contrast, when there is greater potential for consumer sentiment to deteriorate, lending is lowest if the losses from default are split equally between

borrowers and lenders but welfare is maximized should borrowers receive slightly more protection. In general, neither a no-recourse policy nor a full-recourse regime is optimal.

The remainder of the paper is organized as follows. In the next section, we turn to the literature review. We then present the baseline model and discuss its key assumptions and the definition of financial fragility in Section 3. In Section 4, we analyze housing market activity. Section 5 contains the analysis of the bank's best-response allocation to examine mortgage market activity. In Section 6, we focus on how important conditions across markets impact the degree of financial fragility while Section 7 looks at the optimal degree of mortgage recourse. Section 8 concludes. Details of formal arguments are presented in the appendix.

2 Related literature

The model presented in this paper relates to a strand of literature that studies banking fragility in the Diamond and Dybvig (1983) tradition. In particular, Ennis and Keister (2009) highlight the friction of limited commitment on the part of the banking authority for inducing a panic equilibrium, which would otherwise be prevented by an off-equilibrium suspension. Notably, a growing literature extending Ennis and Keister (2009) such as Li (2017) and Gao and Reed (2021, 2022) focuses on studying the existence of run equilibria by assuming that both the asset return and the liquidation cost are exogenous. In comparison to prior contributions, the return to bank investment is endogenous in the current paper as we explicitly model the demand and supply of loans by incorporating a housing and a residential mortgage market. Further, we augment the model to include a secondary market for loans that are supplied by banks to outside investors, similar to Izumi and Li (2021) who study fire sale externalities but in a different context.

Our model is also closely related to the work by Reed et al. (2018) built on the Diamond and Dybvig (1983) model with a market for housing. To be specific, the authors do not focus on bank runs but analyze the impact of the legal environment regarding mortgage default on mortgage market activity and housing prices. Notably, their theoretical framework indicates that when mortgage borrowers have full insurance, housing demand is higher but banks reduce their supply of funding to mortgage markets. To better understand the impact of mortgage recourse, they offer empirical evidence on housing prices at the MSA-level, which suggests that the demand side factors dominate and prices are higher in non-recourse states. By comparison, our main interest is on financial stability, which is absent in the existing literature. Further, we also study aggregate welfare to shed light on the implications for optimal recourse policy.

Regarding evaluating the effects of the legal environment on financial stability, our work contributes to the existing literature such as Peck and Shell (2010) built on Diamond and Dybvig (1983). In particular, the authors aim to assess whether imposing restrictions on the banks' invest-

ment strategies can improve stability by analyzing two regulatory systems for financial intermediaries. Interestingly, Peck and Shell demonstrate that the unified system where banks' portfolios are unrestricted is immune to runs but the separated system of restricted banks from holding illiquid assets is prone to panics. Identifying such an aspect of vulnerability suggests that placing restrictions on banks' holdings of certain investment technologies may have unintended consequences by de-stabilizing the system.

Last but not least, the current paper also relates to the literature that studies the effects of various aspects of legislation on mortgage lending. For example, upon developing a life cycle model to capture some key stylized facts of the recent housing boom and bust in the U.S., Corbae and Quintin (2015) show that increasing punishment for mortgage default leads to less defaults and lower interest rates. Nevertheless, such effects may be weaker in the long term as lower mortgage rates in turn expand access to housing. Recent research also includes Pence (2006) who shows that the size of approved mortgage loans is smaller in states with foreclosure laws favoring borrowers. In other work, Li and Oswald (2017) present evidence that making the deficiency judgment law more defaulter-friendly in Nevada in October 2009 led to material costs on borrowers at the time of loan origination.

3 The model

We extend the Ennis and Keister (2009) version of the Diamond and Dybvig (1983) model to incorporate a housing and a residential mortgage market as in Reed et al. (2018). Further, similar to Allen and Gale (1998), we also augment the framework to include a secondary market where banks subject to liquidity risk can sell loans from their balance sheets. In this manner, both the interest rate in the mortgage market and the price of loans in the secondary market are endogenized. In what follows, we describe the physical environment and define financial fragility in this setup.

3.1 The environment

The economy lasts for three periods, $t = 0, 1, 2$. The economy is populated by a $[0, 1]$ continuum of ex-ante identical consumers indexed by i. Each consumer is endowed with one unit of the all-purpose good at the start of period 0 and has constant relative risk aversion preferences:

$$u\left(c_1, c_2; \omega_i\right) = \frac{\left(c_1 + \omega_i c_2\right)^{1-\gamma}}{1-\gamma},$$

where c_t denotes the consumption level in period $t = 1, 2$. Notably, consumers in the economy are subject to idiosyncratic risk in which they face uncertainty regarding their desire to consume.

As a reflection of this type of uncertainty, the parameter ω_i represents her type and is a privately observed binomial random variable with support $\Omega \equiv \{0, 1\}$. With probability π, an individual i is an impatient consumer, i.e., $\omega_i = 0$, and values consumption in period 1 only; with probability $1 - \pi$, an individual i is patient, i.e., $\omega_i = 1$, and values consumption equally in both periods. Further, consumers' preference types are independent and identically distributed (i.i.d). According to the law of large numbers, the fraction of impatient or patient consumers in the population is also π or $1 - \pi$. Following Diamond and Dybvig (1983), the coefficient of relative risk aversion γ is greater than unity.

In addition to potential depositors, there is a total population B of homebuyers. In particular, homebuyers do not have any endowments in periods 0 and 1 but are endowed with y^b units of the consumption good in the last period. Homebuyers' preferences over consumption and housing services are given by:

$$(1 - q_D) \left[\phi \ln \left(c_2^b\right) + (1 - \phi) \ln \left(h_2\right)\right] + q_D \ln \left(c_2^b\right),$$

where c_2^b and h_2 represent the amount of consumption and housing services respectively. Notably, homebuyers are subject to idiosyncratic risk from the utility of homeownership, which is private information. To be specific, with probability q_D, a homebuyer experiences a negative shock to housing services and only values consumption in period 2; with probability $1 - q_D$, a homebuyer values both consumption and housing on which the weight placed is ϕ and $1 - \phi$.

Lastly, since our objective is to study how mortgage recourse affects financial stability rather than housing prices as in Reed et al. (2018), the supply of homes is perfectly elastic at price p_H.

3.1.1 Financial intermediation and the secondary market for mortgages

As in Diamond and Dybvig (1983), consumers may form coalitions referred to as banks to insure themselves against idiosyncratic liquidity risk. Since the banking sector is perfectly competitive, the objective of the intermediary is to maximize the expected utility of its depositors:

$$W = \int_0^1 E \left[u \left(c_1 \left(i\right), c_2 \left(i\right); \omega_i\right)\right] di.$$

To fulfill this goal, the bank may place funds into a constant-returns-to-scale storage technology in which a unit of the good invested in period 0 yields one unit of the consumption good in either period 1 or period 2. Moreover, it also issues a quantity of two-period mortgages L to its borrowers, i.e., homebuyers, and charges a gross interest rate R. Note, however, that the expected rate of return on loans is λR, where $\lambda = q_D \delta + (1 - q_D)$ and $\delta \in [0, 1]$. To understand why, note that if homebuyers derive utility from housing, which occurs with probability $1 - q_D$, they repay

mortgage obligations in full. Yet, only a proportion δ of borrowed funds is recovered by the financial intermediary if homebuyers receive negative housing shocks and choose to default, which happens with probability q_D.[3] Furthermore, while borrowers experience idiosyncratic risk to utility from housing, the expected mortgage rate is deterministic since there is no aggregate risk at the borrower-level due to the law of large numbers.

Importantly, welfare derived from banking services should be at least as high as consumers' reservation utility so that the existence of banks is justified. That is, resources are not pooled if the bank delivers lower welfare to depositors than financial autarky.[4] To determine the value of consumers' outside options, note that if they choose not to meet at $t = 0$ to set up banks, agents are assumed not to have access to financial markets due to high transactions costs that prevent them from investing directly in credit markets. As a result, only the storage technology is available to individuals. In this vein, let W^A denote the reservation utility derived from one unit of goods invested under autarky, which is characterized by:

$$W^A = \pi u(1) + (1 - \pi) u(1) = u(1). \tag{1}$$

In a similar spirit to that of Ennis and Keister (2009), intermediaries with limited commitment offer flexible payment schedules which adjust to available information at each point in time. It is also worth emphasizing that with full commitment, runs would not be an issue in this setup absent aggregate uncertainty about the total fundamental demand for early consumption. That is, the bank could always eliminate run equilibria by threatening to suspend redemptions once run behavior is identified.

In addition to financial intermediaries, there is a group of outside investors and a secondary market for mortgages to be traded. In particular, if banks have insufficient liquidity holdings to meet depositors' withdrawals in period 1, they can raise liquidity by selling loans to investors at price p_L determined by cash-in-the-market pricing as in Allen and Gale (1998). To be specific, risk-neutral investors who only value consumption in period 2 are each endowed with k^c units of goods in period 1, which represents liquidity in the market. Moreover, investors also have access to the outside option with a gross return of λR and they will purchase assets supplied by banks at prices $p_L \leq 1$ on the secondary market.

[3]For a high degree of tractability, our model captures the different levels of recourse through different fractions of mortgage loans that must be repaid in default. In particular, a higher degree of mortgage recourse requires a larger fraction of mortgage obligations that borrowers need to pay off. However, it is acknowledged that in practice, mortgage recourse allows lenders to recover defaulted loans over and above what they were able to recover from seizing the housing collateral. Yet, if the number of foreclosed houses relative to loans originated is high, intermediaries' income from mortgage recourse would be rather small. Thus, our assumption of rendering the housing value in foreclosure arbitrarily low obtains the upper bound on the relative importance of mortgage recourse.

[4]See also the pre-deposit game in Peck and Shell (2003), among others.

3.2 Bank panics

Following Cooper and Ross (1998) and Peck and Shell (2003), among others, we introduce an exogenous sunspot signal on which depositors can condition their actions. In particular, there are two states of the world, $s \in S \equiv \{\alpha, \beta\}$, with respective probabilities $\{1-q, q\}$. The value of q is assigned strictly between 0 and 1 and thus the potential for a run occurs with a non-trivial probability. Note that the realization of the sunspot state is revealed to depositors immediately at the beginning of period 1 whereas the bank needs to infer the aggregate state from the flow of withdrawals.

Specifically, since a fraction π of depositors in a bank are impatient and have an urgent need to consume in period 1, they will choose to withdraw early with certainty. Thus, if only π depositors show up in period 1, runs do not take place and therefore banks would resume their operations normally. Nevertheless, intermediaries experience runs if more than a fraction π of depositors request withdrawals before they are able to collect realized mortgage income. Among these situations, banks will decide how many mortgages to sell and reschedule the remaining payments to maximize returns to creditors who have not contacted the bank. That is, intermediaries will implement the efficient continuation allocation of resources.

3.3 Withdrawal strategies and partial runs

As previously discussed, at the beginning of period 1, depositors decide whether to contact the bank in period 1 or to wait until period 2 after learning their liquidity needs and the aggregate state. In particular, for each combination of consumers' preference type and the sunspot state, the function for a withdrawal strategy for an agent i at the bank is:

$$y_i : \{0,1\} \times \{\alpha, \beta\} \mapsto \{0,1\}.$$

Specifically, $y_i = 0$ and $y_i = 1$ correspond to withdrawing in periods 1 and 2 respectively.

To proceed, without loss of generality, depositors withdraw funds according to their preference types in state α, which is labeled the good state. Nevertheless, runs may occur in state β, which is called the panic or crisis state. We focus on actions taken by patient depositors, since impatient agents only value consumption in period 1 and will choose to withdraw early with certainty. In this manner, we consider a specific partial-run strategy profile for depositors at the bank as follows:

$$\begin{aligned} &y_i(\omega_i, \alpha) = \omega_i \qquad \text{for } i \in [0,1] \text{ and} \\ &y_i(\omega_i, \beta) = \left\{ \begin{array}{c} 0 \\ \omega_i \end{array} \right\} \quad \text{for } \left\{ \begin{array}{c} i \in [0, \pi] \\ i \in (\pi, 1] \end{array} \right\}. \end{aligned} \tag{2}$$

In this profile, the patient consumer with $i \leq \pi$ at the bank chooses to run in period 1 in the crisis state. As we will show below in our analysis, once the remaining consumption levels are rescheduled after the first π withdrawals, the remaining patient depositors have no incentive to run.[5] In this vein, we next state the formal definition of financial fragility.

Definition 1. *If the strategy profile* (2) *is part of an equilibrium, the bank is said to be fragile.*

Note also that this form of fragility is different from that in Diamond and Dybvig (1983) where depositors run en masse and there is no payment rescheduling. However, the interpretation of relative fragility in the present paper would be the same as that in a model where full bank runs are possible. That is, if the parameter space in which run equilibria exist is larger, then the bank is said to be more fragile.

3.4 Timeline of events

The timing of events is summarized in Figure 1. In period 0, the stock of housing is available to be sold at price p_H. Consumers receive their endowments and decide whether to use the banking service to insure themselves against idiosyncratic liquidity risk. If the expected utility of the risk-sharing arrangement offered by the intermediary is not strictly worse than autarky, consumers then deposit their funds. Furthermore, they choose state-contingent withdrawal strategies after which the bank makes a portfolio choice about how much of its attracted deposits are supplied as mortgage funding. Next, homebuyers seek to obtain mortgage credit from intermediaries and, with their mortgage loans, they purchase homes in the housing market.

At the beginning of period 1, depositors follow their withdrawal plan once they learn their liquidity needs and the realized aggregate state. For tractability, if individuals decide to withdraw in period 1, depositors know their position in the queue in the sense that they will arrive one at a time in the order given by their index and must consume immediately upon arrival. Following Wallace (1988, 1990), the bank is subject to this sequential service constraint where it only observes that a depositor has come and thus the payment to each withdrawing individual can only depend on the number of total withdrawals that have been made. As discussed above, the bank with limited commitment offers a flexible payout scheme. That is, once the bank infers the aggregate state after a fraction π of depositors have withdrawn, payments to the remaining depositors will be rescheduled based on the updated information.

[5] As in Keister (2016), Li (2017), and Gao and Reed (2021), among others, we restrict our attention to a single wave run to simplify notation and concentrate on the impact of the legal environment from provisions for mortgage default on financial instability. One could generalize the model by introducing multiple waves of runs in an environment with a richer sunspot variable as in Ennis and Keister (2010). However, employing such an approach does not alter the main mechanisms and results in the model qualitatively.

In period 2, homebuyers subject to idiosyncratic risk from the utility of homeownership learn whether they derive utility from housing. Conditional on the realization of the value of homeownership and the legal environment regarding mortgage default, homebuyers repay their mortgage obligations. Lastly, intermediaries transfer all of the income they receive from mortgage settlement to consumers who have not withdrawn and the remaining depositors consume afterwards.

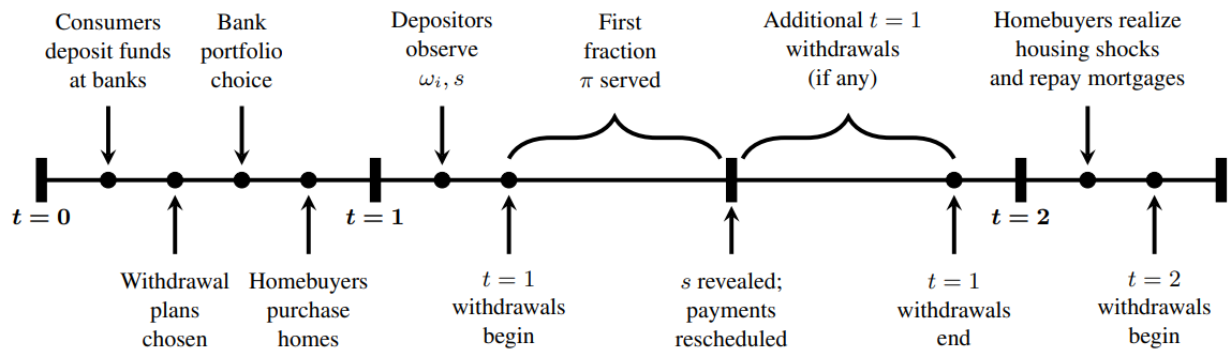

Figure 1: Timeline

4 Housing market activity

We begin by studying the demand for housing, taking the mortgage rate R as given. Note that as homebuyers do not receive any endowments in period 0, they must resort to mortgage funding extended by banks in order to buy homes. Note also that whether financial intermediaries subject to fragility are active in equilibrium depends on how depositors, homebuyers, and banks respond in periods 0 to 2. Consequently, we assume that banks exist while homebuyers borrow funds from intermediaries in period 0 and analyze backwards.

As described before, homebuyers seek access to mortgage financing in period 0 in which they remain uncertain about whether they will value housing in period 2. Notably, when repaying their mortgage obligations, two factors are at work: the first is the utility that they derive from housing services and the second is the legal environment regarding mortgage recourse. To be specific, under scenarios where homebuyers will not obtain any utility from housing, intermediaries are still able to recover a proportion $\delta \in (0, 1]$ of funds that homeowners promised to repay. Nevertheless, if δ takes the value of zero, mortgage borrowers can default without recourse. In this vein, the period-2 consumption level of homebuyers is thus state-contingent where $c_2^b = y^b - Rp_H h_2$ if borrowers repay mortgage obligations in full and $c_2^b = y^b - \delta Rp_H h_2$ if they default on their loans.

Importantly, the amount of housing h_2 will be chosen to maximize a homebuyer's expected utility:

$$\max_{\{h_2\}} (1-q_D)\left[\phi \ln\left(y^b - Rp_H h_2\right) + (1-\phi)\ln\left(h_2\right)\right] + q_D \ln\left(y^b - \delta R p_H h_2\right). \tag{3}$$

The first-order condition characterizing h_2 is given by:

$$\frac{(1-q_D)(1-\phi)}{h_2} = (1-q_D)\,\phi\left(\frac{Rp_H}{y^b - Rp_H h_2}\right) + q_D\left(\frac{\delta R p_H}{y^b - \delta R p_H h_2}\right), \tag{4}$$

where the expected marginal utility from housing is equal to that from consumption. Letting an individual's housing demand function and period-2 consumption be denoted as h_2^d and c_2^{b*}, we then summarize the total demand for mortgage lending $L^d = Bp_H h_2^d$ as follows:

$$L^d = \begin{cases} \frac{B(1-\phi)y^b}{R} & \text{if } \delta = 0 \\ \frac{By^b\left([1+\delta(1-\phi)](1-q_D)+q_D\delta - \left[([1+\delta(1-\phi)](1-q_D)+q_D\delta)^2 - 4\delta(1-q_D)(1-\phi)\right]^{\frac{1}{2}}\right)}{2\delta R} & \text{if } \delta \in (0,1) \\ \frac{B(1-q_D)(1-\phi)y^b}{R} & \text{if } \delta = 1 \end{cases}. \tag{5}$$

To characterize a homebuyer's demand function for mortgages, we proceed to offer the following lemma:

Lemma 1. $\frac{dL^d}{dR} < 0$, $\frac{dL^d}{dy^b} > 0$, *and if* $\delta \in (0,1]$, $\frac{dL^d}{d\delta} < 0$ *and* $\frac{dL^d}{dq_D} < 0$.

It is straightforward that homebuyers' demand for housing and hence loans have standard properties. Specifically, the amount of funding desired is inversely related to the cost of borrowing whereas it is a monotonically increasing function of the level of homebuyers' income in period 2. Further, among situations where borrowers incur some costs in the event of default, lower penalties raise homebuyers' demand for housing and thus mortgages. Lastly, it is also intuitive that if homebuyers are more likely to experience adverse housing shocks, their demand for mortgage lending is lower.

5 Deposit and mortgage market activity

We proceed to examine mortgage market activity where homebuyers seek access to mortgage loans extended by banks that offer payment schedules to help insure depositors against liquidity risk. Note that a burgeoning literature extending Ennis and Keister (2009) typically assumes that financial intermediaries earn an exogenous rate of return on assets. In comparison to prior contributions

such as Li (2017) and Gao and Reed (2021), the return to bank investment is endogenous in the current context as we explicitly model the demand for loans by incorporating a housing and a mortgage market. Further, we also consider the possibility of strategic default on mortgages and can thereby examine how incentives to default threaten financial stability. Finally, we endogenize the price of loans that are sold in the secondary market, similar to Izumi and Li (2021) who study fire sale externalities but in a different context.

In the next subsection, we first derive the best responses of the bank to the strategy profile (2). Specifically, taking the mortgage rate R and price p_L as given due to perfect competition in the banking sector, we investigate how intermediaries make their decisions about the supply of mortgage funding and the repayment scheme. We then compute the market-clearing mortgage rate and the price of loans in the secondary market to determine the allocation associated with the profile specified in (2). Lastly, we study whether the bank is fragile in which the profile (2) emerges as part of an equilibrium.

5.1 The bank's best-response allocation

To begin, the intermediary makes the portfolio allocation decision L and determines how much consumption c_1 it must give to each of the first fraction π of depositors when the aggregate state is unknown. After the bank has inferred the sunspot signal, it can calculate the fraction of the remaining depositors who are impatient and will contact the bank in period 1 based on the strategy profile (2). In particular, since runs do not occur in the good state and all impatient depositors have withdrawn from their bank, no remaining depositors will contact intermediaries. Yet, an extra fraction $(1-\pi)\pi$ of depositors will still demand period-1 consumption if a run has occurred. In this vein, upon the realization of the crisis state, intermediaries choose to give a common amount $c_{1\beta}$ to each remaining impatient depositor in period 1. In addition, each remaining patient depositor who withdraws in period 2 will receive a common amount c_{2s} for $s=\alpha,\beta$. Thus, the quantity of mortgages and the repayment scheme will be chosen to solve:

$$\max_{\{L,c_1,c_{2\alpha},c_{1\beta},c_{2\beta}\}} \pi u(c_1)+(1-q)(1-\pi)u(c_{2\alpha})+q(1-\pi)\left[\pi u(c_{1\beta})+(1-\pi)u(c_{2\beta})\right]. \quad (6)$$

To determine the bank's constraint set, note that it will not be optimal for banks to resort to loan sales in normal times. Otherwise, the bank could hold more liquid assets so that higher consumption levels are provided to all depositors. Furthermore, the bank would not hold liquid assets until period 2 in the crisis state, as it could offer higher payments on deposits by extending more mortgages. In turn, the intermediary may hold liquid assets in state α while selling loans to meet extra period-1 withdrawals upon the revelation of state β. In this regard, the bank's resource

constraints can be expressed as:

$$\begin{aligned} 0 &\leq 1 - L - \pi c_1 && (7) \\ (1-\pi)\, c_{2\alpha} &= (1 - L - \pi c_1) + \lambda R L && (8) \\ 1 - L - \pi c_1 &\leq (1-\pi)\, \pi c_{1\beta} && (9) \\ (1-\pi)^2\, c_{2\beta} &= \lambda R \left(L - \frac{(1-\pi)\, \pi c_{1\beta} - (1 - L - \pi c_1)}{p_L} \right) && (10) \end{aligned}$$

First, all payments made to the first fraction π of depositors come from liquid assets, as suggested by the constraint (7). Furthermore, if such a constraint binds, the bank exhausts all of its holdings of liquid assets upon the revelation of the realized sunspot state. In this regard, the intermediary is said to not hold any excess liquid assets. Otherwise, the bank is still able to make payments in either period 1 in state β or period 2 in state α using the remaining liquid assets. We refer to these situations as settings where the bank holds "excess liquidity." Once the good aggregate state is inferred, the constraint (8) states that the return on deposits in normal times is determined by the standard pro rata division of excess liquid assets held until period 2, if any, and expected mortgage income. Yet, if a run is identified, constraint (9) indicates that all resources held in storage must be consumed. Moreover, the bank needs to sell loans to fulfill additional withdrawal requests in period 1 if this constraint does not bind. In other words, the level of liquidity demanded is equal to the difference between the liabilities to the truly impatient depositors once the crisis state is revealed and the bank's extra liquid assets. Lastly, the period-2 consumption level in the panic state is an even share of the bank's remaining resources, as implied by the constraint (10).

In solving this optimization problem taking the mortgage rate R and price p_L as given, let μ_1, $\mu_{2\alpha}$, $\mu_{1\beta}$, and $\mu_{2\beta}$ denote the multipliers on the resource constraints (7) to (10). The first-order conditions characterizing L, c_1, $c_{2\alpha}$, $c_{1\beta}$, and $c_{2\beta}$ are given by:

$$\begin{aligned} \mu_1 + \mu_{2\alpha} + \frac{\lambda R}{p_L}\mu_{2\beta} - \mu_{1\beta} &= \lambda R \left(\mu_{2\alpha} + \mu_{2\beta} \right) && (11) \\ u'(c_1) &= (\mu_1 + \mu_{2\alpha}) + \frac{\lambda R}{p_L}\mu_{2\beta} - \mu_{1\beta} && (12) \\ (1-q)\, u'(c_{2\alpha}) &= \mu_{2\alpha} && (13) \\ q u'(c_{1\beta}) &= \frac{\lambda R}{p_L}\mu_{2\beta} - \mu_{1\beta} && (14) \\ q u'(c_{2\beta}) &= \mu_{2\beta} && (15) \end{aligned}$$

Notably, the optimality condition regarding the amount of mortgages (11) suggests that the portfolio is held to balance the marginal utility in all states against the average of period-2 marginal

values of resources across states. Aside from that, the first-order condition for the early payment c_1, (12), implies that the bank equates the marginal utility of early payments to the marginal value of resources taking into account all possible outcomes across both sunspot states. In particular, the term $\frac{\lambda R}{p_L}\mu_{2\beta}$ on the right-hand-side of equation (12) indicates that the bank weighs the return to mortgages λR against the loan price p_L if the crisis state emerges. Specifically, if both the degree of borrower protection and the possibility of strategic default are low, banks offer lower deposit rates in the short-term. Nevertheless, the reverse is the case if the price of loans in the secondary market is higher. In addition, the last three ex-post risk-sharing conditions (13) to (15) indicate how the bank seeks to reallocate resources to the remaining fraction $1-\pi$ of depositors after the revelation of the aggregate state. Taken together, these conditions imply that the ex-post optimal payout scheme entails: $\frac{c_{2\beta}}{c_{1\beta}} = \left(\frac{\lambda R}{p_L}\right)^{\frac{1}{\gamma}}$ or $\frac{c_{2\beta}}{c_{1\beta}} < \left(\frac{\lambda R}{p_L}\right)^{\frac{1}{\gamma}}$, depending on whether mortgage loans are sold should the crisis state be revealed.

Overall, there are three distinct scenarios as described below. Under Scenario I, the bank only holds liquid assets for the first fraction π of agents in state α and sells loans to meet any additional period-1 withdrawals beyond the first π depositors in state β, i.e., $\mu_1 > 0$ and $\mu_{1\beta} = 0$. Under Scenario II, however, some of the returns from holdings of short-term assets are paid to patient consumers in period 2 in normal times but loan sales will also occur should a run emerge, i.e., $\mu_1 = 0$ and $\mu_{1\beta} = 0$. Under Scenario III, the bank holds a sufficiently liquid portfolio so that any withdrawal demand is met without resorting to loan sales, i.e., $\mu_1 = 0$ and $\mu_{1\beta} > 0$.

	State α	State β
Scenario I	No-excess liquidity	Loan sales
Scenario II	Excess liquidity	Loan sales
Scenario III	Excess liquidity	No loan sales

Table 1: Three possible scenarios

To summarize, the preceding analysis demonstrates the best responses of intermediaries to the strategy profile (2) where there are three possible allocations in total. Letting the superscripts I, II, and III designate the outcomes under each scenario, we can express the best-response allocation as three different vectors, where each vector contains information about the bank's portfolio choice and payments to depositors:

$$c^* \equiv \left\{L^*, c_1^*, c_{2\alpha}^*, c_{1\beta}^*, c_{2\beta}^*\right\} \quad \text{for} * = I, II, III.^6$$

Note that the mortgage lending and consumption levels specified above are jointly defined by conditions (11) to (15) and the resource constraints (7) to (10).

[6] See the Appendix for the calculated mortgage lending and consumption levels.

In what follows, we turn to determine conditions under which the profile (2) emerges as part of an equilibrium. To begin, we only focus on actions taken by patient depositors since impatient agents with an urgent need to consume will choose to withdraw in period 1 with certainty. We then begin by considering the behavior of patient individuals with $i > \pi$. Specifically, as there is no uncertainty once the aggregate state is identified, the bank sets returns on deposits such that $c^*_{2\beta} > c^*_{1\beta}$ under the ex-post allocation of consumption. As a result, withdrawing in period 2 is a strictly dominant strategy for a patient depositor $i > \pi$.

Next, we consider separately two possible cases for patient agents who have the chance to withdraw before the state of nature is inferred by the bank. In particular, a patient depositor $i \leq \pi$ receives $c^*_{2\alpha}$ should the good state be realized and c^*_1 if she contacts the bank in period 1. In this regard, it can be shown that $c^*_{2\alpha} > c^*_1$ across all scenarios and thus no runs occur in normal times. By comparison, if the panic state is realized at the start of period 1, a patient agent $i \leq \pi$ anticipates to receive $c^*_{2\beta}$ if she waits until period 2 but c^*_1 if she joins the run. Consequently, the partial-run strategy profile specified in (2) is part of an equilibrium if and only if $c^*_1 \geq c^*_{2\beta}$.

Notably, allocations under Scenarios I and II can be susceptible to self-fulfilling behavior in the sense that there is scope for the fragility condition $c^*_1 \geq c^*_{2\beta}$ to hold whereas the payoff schedule under Scenario III is not. To see why, note that if the bank holds a sufficiently liquid portfolio so that loan sales are not needed in state β, $1 - L^{III} - \pi c^{III}_1 = (1-\pi)\pi c^{III}_{1\beta}$ and $(1-\pi)^2 c^{III}_{2\beta} = RL^{III}$. Substituting these two conditions into constraint (8) and some simplifying algebra yields $\frac{c^{III}_{2\alpha}}{c^{III}_{2\beta}} = \pi \frac{c^{III}_{1\beta}}{c^{III}_{2\beta}} + (1-\pi) < 1$, as $c^{III}_{1\beta} < c^{III}_{2\beta}$. Furthermore, $c^{III}_{2\alpha} < c^{III}_{2\beta}$ and $c^{III}_1 < c^{III}_{2\alpha}$ jointly imply that $c^{III}_1 < c^{III}_{2\beta}$, which violates the incentive to run condition $c^*_1 \geq c^*_{2\beta}$. Consequently, we confine to Scenarios I and II throughout the remainder of the analysis.

We next discuss the bank's best-response allocation on the equilibrium path of play. Notably, it can be shown that when runs are less likely to occur, i.e., $q \in \left(0, q^I\right)$ where $q^I = \frac{1}{1+\left(\frac{1-p_L}{\lambda R-1}\right)\left[\pi\left(\frac{\lambda R}{p_L}\right)+(1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1}{\gamma}}\right]^{\gamma}}$ and $q^I < 1$ if $p_L < 1$, it would be optimal for banks to hold liquid assets for the first fraction π of agents only but sell loans to meet the extra liquidity demand in state β. Nevertheless, if the potential for run behavior is higher, i.e., $q \in \left[q^I, q^{II}\right)$, where $q^{II} = \frac{1}{1+\left(\frac{1-p_L}{\lambda R-1}\right)\left[\pi+(1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1}{\gamma}}\right]^{\gamma}}$, banks hold excess liquid assets as a precaution to prepare for crises. We then offer the following lemma:

Lemma 2. *If $q \in \left(0, q^I\right)$, the solution to the bank's optimization problem belongs to Scenario I. Yet, if $q \in \left[q^I, q^{II}\right)$, then it belongs to Scenario II.*

To proceed, we summarize the comparative statics of the loan supply function L^* below. Notably, such an analysis relates to studies that examine banks' portfolio choices with a positive run

probability in the standard Diamond-Dybvig framework. For example, while Cooper and Ross (1998) sought to establish conditions where the bank holds excess liquidity, Ennis and Keister (2006) clarify part of the analysis in Cooper and Ross by showing that precautionary liquid assets against runs will not be held. Further, Ennis and Keister (2006) demonstrate that investment may be increasing in the possibility of a crisis, but they only do so for economies where the coefficient of relative risk aversion is less than one and in a much different context. More recently, Li (2017) studies the relationship among interest rates, portfolio choices, and financial instability in a version of the Diamond and Dybvig model with limited commitment. Though Li (2017) offers the first example where intermediaries holding excess liquid assets emerge in equilibrium, there has not been any discussion about how economic conditions affect the amount of bank investment. As we ultimately seek to study equilibrium mortgage rates simultaneously with the potential for fragility, our detailed approach to characterizing loan supply is necessary.

For the following set of results, note that there exists a cutoff expected mortgage return under Scenario II defined in the appendix below (above) which $\frac{dL^{II}}{d(\lambda R)} > (<) 0$. As $\frac{d(\lambda R)}{dR} > 0$, $\frac{d(\lambda R)}{d\delta} > 0$, and $\frac{d(\lambda R)}{dq_D} < 0$, we then offer Lemma 3 as follows:

Lemma 3. *Suppose that run equilibria exist. Under this condition:*

i. If $q < q^I$, $\frac{dL^I}{dR} < 0$, $\frac{dL^I}{d\delta} < 0$, $\frac{dL^I}{dq} > 0$, *and* $\frac{dL^I}{dq_D} > 0$*;*

ii. If $q \geq q^I$, $\frac{dL^{II}}{dR} > (<) 0$ *if* $R < (>) R^I$, $\frac{dL^{II}}{d\delta} > (<) 0$ *if* $\delta < (>) \delta^I$, $\frac{dL^{II}}{dq} < 0$, $\frac{dL^{II}}{dq_D} < (>) 0$ *if* $q_D > (<) q_D^I$*, where* R^I, δ^I, *and* q_D^I *are defined in the appendix.*

Notably, if the prospect of a run is low where intermediaries do not possess excess liquidity, banks hold relatively large amounts of mortgages and deposit rates in the long-term would be relatively high. As a result, if mortgage market conditions are better, then banks focus more on providing risk-sharing by offering higher deposit rates to the earliest depositors, indicating that the loan supply L^I is downward sloping in R. In this manner, conditions in the mortgage market bear significant implications for deposit market activity. Moreover, as long as intermediaries are able to recover more income in the event of foreclosure, they respond by offering higher deposit rates prior to inferring the aggregate state and lending less. By comparison, if the potential for run behavior to occur is higher, banks become more prudent in issuing short-term liabilities due to uncertainty about whether a panic will occur. Hence, more resources are allocated to mortgage lending so that banks can offer higher deposit returns in either sunspot state. Similar behavior emerges if the mortgage default rate is higher: banks lower payoffs to the first fraction π of depositors, which in turn affects the provision of mortgages.

Yet, based upon the discussion prior to Lemma 3, the opposite to the above occurs in a more crisis-prone economy when the expected mortgage rate is relatively low. To be specific, as banks

holding excess liquid assets as a precaution against runs supply relatively less loans than in settings where the likelihood of a crisis is low, they issue more mortgages if interest rates are higher over relatively low mortgage rates. Nevertheless, the loan supply curve exhibits backward-bending behavior if the interest rate and thus the expected mortgage return is sufficiently high. Under these circumstances, banks prefer to lend less at higher rates of return on loans as the income from mortgages would be particularly high and by doing so, banks improve risk-sharing for depositors.

To proceed, when the expected interest rate is sufficiently low under Scenario II, less funding is extended if it is less costly for borrowers to default. In turn, if higher penalties for default are imposed, banks are inclined to issue more loans by holding less excess liquid assets as a cushion against panics. It is also worth emphasizing that mortgage supply is lower should the run probability be higher when the prospect of a panic is high. The intuition is straightforward: intermediaries behave in a more conservative manner by maintaining more excess liquidity to guard against the potential for run behavior to emerge. Lastly, if homebuyers are more likely to strategically default on their mortgage obligations, the supply of funding is lower in settings of low expected mortgage returns but the opposite emerges over high expected interest rates on loans.

Before turning to examine the equilibrium mortgage rate and price of loans on secondary markets, note that the backward-bending part of the mortgage supply curve under Scenario II described above introduces additional complexity into our analysis below. Thus, in order to retain a high degree of tractability, we focus our attention on settings where the expected mortgage rate is relatively low when there is a high propensity to panic. Further, in comparison to Scenario I, interest rates are relatively high because banks issue comparatively less mortgages. This pattern is reinforced over the backward-bending part of the supply curve. Based upon our numerical examples below, we generally find that equilibrium mortgage rates over this segment of the supply curve would be implausibly high – well in excess of average 30-year fixed mortgage rates that have been observed during the postwar period in the United States.[7] Consequently, we concentrate on discussing the implications of behavior over the upward-sloping part of the supply curve and provide conditions where there is a unique equilibrium mortgage rate in Proposition 1 below.

5.2 Equilibrium mortgage rate and price of loans on secondary markets

To see how the equilibrium mortgage rate is determined, first note that the demand for mortgages L^d comes from homebuyers who seek to obtain loans from intermediaries in the initial period to purchase homes in the housing market. Note also that mortgage funding L^I or L^{II}, which critically hinges on the run probability, is supplied by banks that make portfolio choices to help

[7] Based on data from FRED, for example, the annual average 30-year fixed mortgage rate from 2000 to 2021 ranged from 2.96% to 8.05%. In addition, since 1971, the highest rate was 16.64% in 1981. Notably, as we will show in our examples below, the cutoff R^I is far greater than the values of these data points.

insure depositors against idiosyncratic liquidity risk. In this vein, the market-clearing condition for mortgages is given by:

$$L^d = L^* \quad \text{for} * = I, II. \tag{16}$$

Recalling that R^I is defined in Lemma 3, we then establish existence of an equilibrium in the mortgage market in the following proposition:

Proposition 1. *Suppose that p_L is given. Under this condition, if $y^b > \underline{y}^I$, where $\underline{y}^I = \frac{2\delta(1-\pi)}{B\lambda\left([1+\delta(1-\phi)](1-q_D)+q_D\delta-\left(([1+\delta(1-\phi)](1-q_D)+q_D\delta)^2-4\delta(1-q_D)(1-\phi)\right)^{\frac{1}{2}}\right)}$ for $\delta \in (0,1)$ or $\underline{y}^I = \frac{1-\pi}{B(1-q_D)(1-\phi)}$ for $\delta = 0, 1$ and $\underline{y}^I : R^* = \frac{1}{\lambda}$, then there exists a unique mortgage market equilibrium under Scenario I. In addition, if $y^b \in \left(\underline{y}^I, \bar{y}^{II}\right)$, where $\bar{y}^{II} : R^* = R^I$, then there exists a unique mortgage market equilibrium under Scenario II.*

The equilibrium of the mortgage market under Scenario I requires the expected interest rate to be higher than the investment return under autarky. Further, conditional on the existence of such equilibria, the same lower bound on a homebuyer's income $\underline{y}^I$ applies under Scenario II. As argued before, we focus on the upward-sloping part of the supply curve L^{II}, which requires that $y^b \in \left(\underline{y}^I, \bar{y}^{II}\right)$. Hence, the equilibrium in the mortgage market is unique.

Next, based upon the previous analysis, the supply of mortgages depends on important factors such as the potential for run behavior to emerge and the legal environment over mortgage default. As a result, the equilibrium interest rate R^* depends on the prospect of a panic and the degree of mortgage recourse.

Proposition 2. *Suppose that p_L is given and run equilibria exist. Further, suppose that $y^b > \underline{y}^I$ under Scenario I and $y^b \in \left(\underline{y}^I, \bar{y}^{II}\right)$ under Scenario II. Under these conditions, $\frac{dR^*}{dq} < (>) 0$ under Scenario I (II). In addition, $\frac{dR^*}{dy^b} > 0$ and $\frac{dR^*}{d\delta} < 0$ in either scenario.*

The above proposition highlights that R^* is lower over initially low run probabilities but is higher if crises are sufficiently likely to occur. To see this precisely, suppose that the propensity to panic is relatively low where banks only hold enough liquidity to cover liabilities to the first fraction π of depositors. For a given mortgage rate in these situations, intermediaries reduce their short-term payments as the likelihood of a run increases and thus a larger amount of mortgage funding will be extended to homebuyers. Given that the demand for loans is invariant to changes in the crisis probability, the mortgage market clears when the gross interest rate R^* is lower. By comparison, should panics be more likely and banks possess extra liquidity, intermediaries become more prudent when supplying mortgage funding if the potential for run behavior is higher. Consequently, R^* is an increasing function of q under Scenario II.

Further, it is straightforward that the bank's lending schedule is independent of the housing market parameter y^b. In this vein, the mortgage rate in equilibrium will be higher if there is higher demand for loans. In this regard, R^* is a strictly increasing function of y^b.

More importantly, regardless of the probability of a financial crisis, intermediaries will be compensated with higher interest rates if the cost of default for borrowers is lower. To understand why, recall from Lemma 1 that the demand for mortgage loans is higher should default be less costly. Note also that over initially low run probabilities where banks do not hold excess liquidity, mortgage supply is higher. Due to a relatively larger increase in the amount of loans demanded than supplied,

$$\frac{dL^d}{d\delta} < \frac{dL^I}{d\delta} < 0,$$

the mortgage rate is higher. Moreover, at lower penalties for default, banks holding a precautionary buffer of liquidity in a more crisis-prone economy will also obtain higher interest rates since less loans are extended, as implied by Lemma 3.

In order to draw further insights into how mortgage lending depends on the bank's susceptibility to fragility and the extent of legal recourse, we resort to numerical simulations below due to the complexity of these exercises. For this purpose, consider the set of parameters $\left(\pi, \gamma, y^b, \phi, B, q_D, p_L\right) = (0.5, 4, 1.85, 0.7, 1, 2.5\%, 0.7)$ along with $q = 5\% < q^I$, $q = q^I$, and $q = 15\% > q^I$ in Table 2. Under the parameter values considered, there is only one solution to the bank's problem at each value of δ under Scenario II because the demand and supply curves only intersect once.[8] Interestingly, there exist two distinct patterns of lending behavior at higher costs of mortgage default and run probabilities across scenarios.

[8]Specifically, $R^I = 1.378$, 1.371, 1.364, 1.357, 1.350, and 1.343 at $\delta = 0$, 0.2, 0.4, 0.6, 0.8, and 1, respectively.

	$q < q^I$		$q = q^I$		$q > q^I$	
δ	$L^d = L^I$	(R^*, p_L)	$L^d = L^*$	(R^*, p_L)	$L^d = L^{II}$	(R^*, p_L)
0	0.481752	(1.152045, 0.7)	0.486777	(1.140152, 0.7)	0.454021	(1.222410, 0.7)
.1	0.481555	(1.150386, 0.7)	0.486657	(1.138327, 0.7)	0.454205	(1.219658, 0.7)
.2	0.481392	(1.148514, 0.7)	0.486557	(1.136323, 0.7)	0.454356	(1.216856, 0.7)
.3	0.481266	(1.146411, 0.7)	0.486480	(1.134125, 0.7)	0.454472	(1.213999, 0.7)
.4	0.481181	(1.144057, 0.7)	0.486428	(1.131717, 0.7)	0.454551	(1.211080, 0.7)
.5	0.481140	(1.141429, 0.7)	0.486402	(1.129079, 0.7)	0.454590	(1.208093, 0.7)
.6	0.481146	(1.138503, 0.7)	0.486406	(1.126191, 0.7)	0.454583	(1.205029, 0.7)
.7	0.481205	(1.135253, 0.7)	0.486443	(1.123030, 0.7)	0.454529	(1.201882, 0.7)
.8	0.481322	(1.131648, 0.7)	0.486514	(1.119572, 0.7)	0.454420	(1.198643, 0.7)
.9	0.481502	(1.127657, 0.7)	0.486624	(1.115788, 0.7)	0.454253	(1.195302, 0.7)
1	0.481752	(1.123244, 0.7)	0.486777	(1.111648, 0.7)	0.454021	(1.191849, 0.7)

Table 2: The impact of δ and q on L^* and R^*

To begin, to shed light on the impact of higher penalties for default on equilibrium lending, we start by discussing cases under Scenario I where the bank holds liquid assets for the first fraction π of depositors only. Among these circumstances, moving from a situation where borrowers can default without recourse to some costs of default causes mortgage lending to decline but the opposite occurs if penalties are sufficiently costly. To understand why, note that there are two competing effects at work. First, higher penalties for mortgage default lower the demand for mortgages by borrowers. Though interest rates fall due to lower demand, the equilibrium volume of lending is still lower over the low range of δ. Nevertheless, at higher costs of default, mortgage rates would be lower to the point where borrowers demand more mortgage funding even though the penalties are significant. Interestingly, mortgage lending where full recourse provisions are in place is exactly the same as that should borrowers have full insurance against default because the low mortgage rate exactly compensates for the lack of protection for borrowers from recourse.

In contrast, under Scenario II in which the bank holds a more liquid portfolio to prepare for runs, equilibrium lending reaches the highest level at intermediate default costs. To see why lending is higher over the initially lower range of penalties for default, recall from Lemma 1 (3)

that mortgage demand (supply) is decreasing (increasing) in both δ and R. Though a higher cost of default tends to lower the demand for loans, the increase in supply will result in lower mortgage rates, leading to higher equilibrium lending as long as the level of protections for borrowers is relatively high. Nevertheless, the pattern regarding equilibrium lending begins to reverse should penalties for default be high enough. Yet, similar to that in a less crisis-prone economy, mortgage lending is exactly the same across no-recourse and full-recourse regimes due to changes in the mortgage rate that completely compensate for default risk.

It is also worth noting that the effects of the interest rate on mortgages appear to dominate when examining how the likelihood of a run impacts the volume of lending in equilibrium. That is, given that the interest rate on loans is decreasing (increasing) in q under Scenario I (II), mortgage market activity is higher over low crisis probabilities, i.e., $q \leq q^I$, but is lower should runs be highly likely to occur, i.e., $q \geq q^I$.

To proceed, we further examine how the mortgage rate and lending are affected when the price of loans in the secondary market (p_L) is endogenized. To this end, let $k^* \equiv (1-\pi)\,\pi c^*_{1\beta} - (1 - L^* - \pi c^*_1)$ represent the amount of loans measured in units of goods supplied in the secondary market, where k^I and k^{II} are increasing functions of p_L for a given R. Then, the price p_L is determined by the following market-clearing condition:

$$k^c = k^* \quad \text{for} * = I, II. \tag{17}$$

Due to the complexity of characterizing the impact of δ and q on mortgage rates and lending, the following set of parameters $\left(\pi, \gamma, y^b, \phi, B, q_D, k^c\right) = (0.5, 4, 1.85, 0.7, 1, 2.5\%, 0.2)$ along with

$q = 5\% < q^I$, $q = q^I$, and $q = 15\% > q^I$ is adopted in Table 3.

	$q < q^I$		$q = q^I$		$q > q^I$	
δ	$L^d = L^I$	(R^*, p_L)	$L^d = L^*$	(R^*, p_L)	$L^d = L^{II}$	(R^*, p_L)
0	0.481514	(1.152614, 0.709560)	0.486805	(1.140086, 0.701845)	0.475463	(1.167284, 0.738727)
.1	0.481315	(1.150960, 0.709625)	0.486684	(1.138260, 0.701795)	0.475467	(1.165118, 0.738251)
.2	0.481151	(1.149088, 0.709680)	0.486584	(1.136259, 0.701755)	0.475471	(1.162818, 0.737862)
.3	0.481024	(1.146988, 0.709720)	0.486507	(1.134061, 0.701720)	0.475473	(1.160382, 0.737561)
.4	0.480937	(1.144635, 0.709750)	0.486454	(1.131654, 0.701700)	0.475474	(1.157789, 0.737358)
.5	0.480895	(1.142008, 0.709765)	0.486429	(1.129017, 0.701692)	0.475474	(1.155028, 0.737260)
.6	0.480902	(1.139081, 0.709760)	0.486433	(1.126129, 0.701694)	0.475474	(1.152084, 0.737276)
.7	0.480962	(1.135829, 0.709745)	0.486469	(1.122969, 0.701705)	0.475473	(1.148939, 0.737416)
.8	0.481080	(1.132218, 0.709705)	0.486541	(1.119510, 0.701735)	0.475472	(1.145573, 0.737695)
.9	0.481263	(1.128217, 0.709644)	0.486652	(1.115726, 0.701783)	0.475468	(1.141969, 0.738125)
1	0.481514	(1.123798, 0.709560)	0.486805	(1.111586, 0.701845)	0.475463	(1.138102, 0.738727)

Table 3: The impact of δ and q on L^*, R^*, and p_L^*

Notably, it can be observed that, much as in the previous table, variations in equilibrium lending and mortgage rates with respect to the cost of default and the run probability are similar. In this regard, our previous results appear to be robust to endogenizing loan prices on the secondary market.

Moreover, based upon these patterns of lending behavior, the amount of mortgages supplied in the secondary market may change accordingly, which bears important implications for the price of mortgages p_L^*. On the one hand, under Scenario I, i.e., $q < q^I$, L^I is lower over initially low values of δ but is higher should δ be high enough and so is k^I. Given that k^I is strictly increasing in p_L, as discussed above condition (17), the equilibrium mortgage price p_L^* increases (decreases) in the cost of default when protections for homebuyers are high (low). On the other hand, according to changes in mortgage lending and hence the amount of loans sold in the secondary market under Scenario II, i.e., $q > q^I$, the mortgage price is decreasing (increasing) in δ over low (high) penalties for default.

Nevertheless, it is also worth noting that the amount of mortgages sold in the secondary market does not necessarily follow the behavior of lending activity. As illustrated by the set of examples

where $q = q^I$, though the level of mortgage funding is low (high) at low (high) costs of default, the intermediary finds it optimal to raise (lower) ex-post payments contingent on a run by selling more (less) mortgages from the balance sheets. As a result, the loan price p_L^* would be low at relatively low costs of mortgage default but it is high otherwise.

5.3 Equilibrium and the scope for run equilibria

Before turning to study how financial stability is affected by both housing and mortgage market activity, we proceed to define the equilibrium of the withdrawal game. To this end, first recall that y denotes a complete profile of strategies for all depositors at the bank. In addition, let χ represent the repayment strategy for the bank. Note that we study equilibria of a withdrawal game where: (i) each depositor determines y_i to maximize her expected utility $\sigma_i(\chi, (y_i, y_{-i}), R)$; (ii) the bank chooses χ to maximize the expected utility of its depositors $U(\chi, y, R)$; (iii) each agent's strategy is a best response to the strategies of others. Thus, the formal definition of an equilibrium is given by:

Definition 2. *The equilibrium of the withdrawal game at the bank is the profile of strategies* (χ^*, y^*) *and the mortgage rate* R^* *such that:*

i. $\sigma_i\left(\chi^*, \left(y_i^*, y_{-i}^*\right), R^*\right) \geq \sigma_i\left(\chi^*, \left(y_i, y_{-i}^*\right), R^*\right)$ *for all* y_i *and all* $i \in [0,1]$*;*

ii. $U(\chi^*, y^*, R^*) \geq U(\chi, y^*, R^*)$ *for all* χ*;*

iii. R^* *satisfies the market-clearing condition* (16).

In what follows, we study the parameter space in which allocation c^* is obtained such that the above results hold. To this end, it is worth noting that there exists a maximum run probability with which the fragility condition $c_1^* \geq c_{2\beta}^*$ is satisfied under each scenario. To be specific, let q_F^* for $* = I, II$ denote the threshold prospect of a panic consistent with the run equilibrium. As is common in the literature, these two cutoffs serve as natural measures of financial fragility where banks delivering higher welfare than autarky are said to be more unstable if q_F^* is higher because the scope for fragility is larger. Furthermore, recall that $W^A = u(1)$, which is given by (1), and in such an environment, intermediaries are always able to raise depositors' welfare above what they would have achieved under financial autarky. Furthermore, given that q^I defined above Lemma 2 denotes the critical run probability below which banks do not hold excess liquid assets, q_F^I measures the degree of instability if and only if $q_F^I < q^I$. Otherwise, in economies where $q^I < q_F^I$, the threshold q_F^{II} applies.

In seeking to address the scope for fragility, we now examine our primary question of interest: How do conditions in the mortgage market such as the legal environment over mortgage default

impact the degree of financial fragility? In a related setup where the asset return R is exogenous, Li (2017) studies how a change in the term structure of interest rates affects the vulnerability of banks to a run. Nevertheless, as studied earlier, the return to bank investment is endogenous in the present model as we incorporate both housing and mortgage markets. In this vein, we are able to analyze the role of not only supply-side but also demand-side factors for financial fragility, which is novel to the existing literature. In addition, as fixing the price of mortgages p_L would be rather special, we study the degree of stability where intermediaries in a liquidity crisis sell loans at the same time which causes the loan price and the bank's vulnerability to a run to change simultaneously.

In particular, Figure 2 plots the scope for run equilibria to exist as a function of the probability of a financial crisis q and the measure of mortgage recourse δ. Notably, the figure illustrates the threshold values of q, that is, q_F^I, with which run equilibria exist. Should the prospect of a panic be higher than these cutoffs, the incentive to run condition is violated. To be specific, we construct examples with parameters $\left(\pi, \gamma, y^b, \phi, B, q_D, k^c\right) = (0.325, 4, 2.5, 0.7, 1, 2.5\%, 0.2237)$ under which $q_F^I < q^I$ and hence q_F^I is a valid measure for the degree of instability. Note that the choice of the parameter values such as those of π, y^b, and k^c differs from Table 3 where $q_F^I > q^I$ and run equilibria existed $\forall q \in \left(0, q^I\right)$ in our previous examples. In turn, there is a somewhat smaller scope for fragility in the current set of simulations since $q_F^I < q^I$. Under such parameter values considered, there is a non-monotonicity of financial fragility with respect to the penalties for default where the degree of instability reaches the highest level at the intermediate cost of default.

To see this precisely, note that under this set of simulations, the amount of mortgage lending is low at sufficiently low costs of default. Nevertheless, given that the bank chooses to offer high payments to the remaining truly impatient depositors in the aftermath of a crisis by resorting to more loan sales, the mortgage price on the secondary market is lower. Though period-2 payoffs are also high due to more expected mortgage income, such an increase is dominated by the returns on early demandable deposits, leaving the bank more susceptible to a crisis. Conversely, once the penalties for default are sufficiently high, the opposite to the above occurs. Specifically, by reducing payouts to the earliest consumers, banks supply more funding at low interest rates. Further, relatively less loans are sold on the secondary market during a panic, increasing payments on deposits in period 2 in the crisis state. In these situations, depositors' inclination to run on banks is weak. Interestingly, due to the low mortgage rate, the scope for run equilibria where full recourse provisions are in place is exactly the same as that should borrowers have full insurance against default.

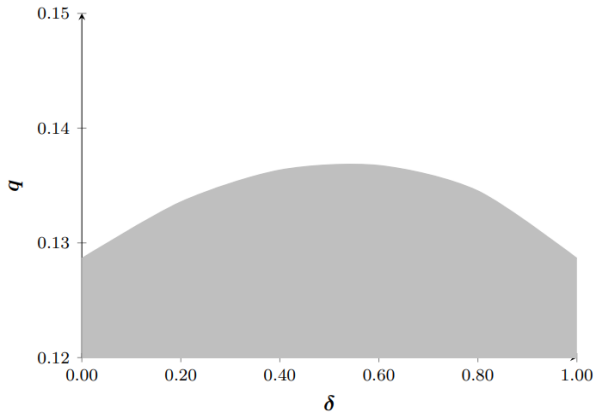

Figure 2: The scope for run equilibria under Scenario I

We proceed to examine banking stability under scenarios where intermediaries find it optimal to hold precautionary liquid assets. For this purpose, we depict a set of the threshold run probability in Figure 3 by using the same set of the parameter values $\left(\pi, \gamma, y^b, \phi, B, q_D, k^c\right) = (0.5, 4, 1.85, 0.7, 1, 2.5\%, 0.2)$ as in Table 3. Notably, the graph illustrates that there exhibits a non-linear relationship between the cutoff value of the prospect of a panic q_F^{II} and δ but the resulting pattern is opposite to that in Figure 2. To understand this non-monotonicity, first note that when the cost of default is higher over initially high protection for borrowers, banks possess less liquid assets while reducing the supply of mortgages. Since a higher rate of return on deposits to the earliest consumers is offered, intermediaries resort to more loan sales in order to meet additional withdrawal requests by truly impatient agents upon the identification of the crisis state. Yet, due to larger penalties for default, more mortgage income and thus period-2 payments are expected. Given that the increase in ex-post payoffs dominates that in earliest returns on deposits, the degree of financial fragility is lower.

In contrast, consumers' incentives to run on the bank are stronger over a higher range of the degree of mortgage recourse. The intuition is as follows. By lowering payments prior to inferring the aggregate state, intermediaries hold more excess liquidity and increase their mortgage lending. While banks engage in less loan sales, which leads to an increase in mortgage price on the secondary market, ex-post payments on deposits are lower owing to the reason that the expected return to loans is low. As the magnitude of the decrease in period-2 payoffs is larger than that in early demandable deposits, the degree of financial fragility is higher in the sense that the cutoff value q_F^{II} is a strictly increasing function of δ. Note, however, that, similar to Figure 2, the degree of fragility is exactly the same across a no-recourse policy and a full-recourse regime.

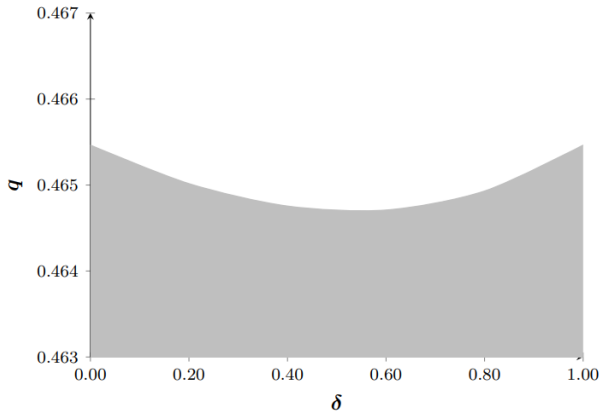

Figure 3: The scope for run equilibria under Scenario II

6 Welfare and optimal recourse policy

In this section, we conduct welfare analysis to shed light on the corresponding implications for recourse policy. As the cost of default varies, activity in the housing, mortgage, and secondary markets changes. Recall that if intermediaries do not have the ability to impose large penalties for default, they generally obtain higher rates as compensation for lower levels of mortgage recourse. Further, the amount of loans supplied and the price on secondary markets will be affected due to the different patterns of lending behavior in the mortgage market, which in turn impacts investors' capital gains. At the aggregate level, the optimal degree of mortgage recourse balances the welfare gains and losses across the different groups of individuals.

Before turning to understand the welfare implications from the legal landscape in the mortgage sector, we first define aggregate welfare $\mathcal{W}^*$ as follows. To be specific, it consists of the sum of depositors', homebuyers', and investors' expected utilities:

$$\begin{aligned}\mathcal{W}^* \equiv & \underbrace{\pi u\left(c_1^*\right)+\left(1-q_F^*\right)(1-\pi)\, u\left(c_{2\alpha}^*\right)+q_F^*(1-\pi)\left[\pi u\left(c_{1\beta}^*\right)+(1-\pi)\, u\left(c_{2\beta}^*\right)\right]}_{=W^*} \\ & +\underbrace{B\left\{(1-q_D)\left[\phi \ln\left(c_2^{b*}\right)+(1-\phi)\ln\left(h_2^d\right)\right]+q_D \ln\left(c_2^{b*}\right)\right\}}_{=W_B^*}+\underbrace{\lambda R^* \frac{k^c}{p_L}}_{=\Pi^*},\end{aligned} \tag{18}$$

where all participants are given equal weight. Notably, we evaluate the aggregate welfare level $\mathcal{W}^*$ at the cutoff measure of fragility for the following reason. When there is greater potential for consumer sentiment to deteriorate, depositors' expected utility is lower due to lower welfare in the event of a run than in normal times. By taking into account the maximum run probability

consistent with run equilibria, we highlight how the extent of legal recourse along with the degree of financial instability impact social welfare.

Due to the complexity of deriving the results analytically, we resort to numerical simulations to study optimal mortgage recourse. To this end, consider the set of parameter values $\left(\pi, \gamma, y^b, \phi, B, q_D, k^c\right) = (0.325, 4, 2.5, 0.7, 1, 2.5\%, 0.2237)$ adopted for Figure 2. In this set of simulations, variations in lending activity and loan prices on the secondary market are again similar to those where $q = q^I$ in Table 3.

δ	L^I	(R^*, p_L^*)	W^*	W_B^*	Π^*	$\mathcal{W}^*$
0	0.658437	(1.139059, 0.984280)	-0.273232	0.237265	0.252405	0.216438
.1	0.658319	(1.137159, 0.983784)	-0.272852	0.237000	0.252758	0.216906
.2	0.658220	(1.135096, 0.983374)	-0.272537	0.236756	0.253050	0.217269
.3	0.658144	(1.132852, 0.983058)	-0.272295	0.236535	0.253276	0.217517
.4	0.658092	(1.130414, 0.982844)	-0.272129	0.236341	0.253429	0.217641
.5	0.658067	(1.127762, 0.982740)	-0.272049	0.236177	0.253502	0.217629
.6	0.658070	(1.124882, 0.982756)	-0.272061	0.236045	0.253490	0.217474
.7	0.658107	(1.121747, 0.982905)	-0.272177	0.235951	0.253385	0.217159
.8	0.658177	(1.118338, 0.983199)	-0.272401	0.235899	0.253175	0.216673
.9	0.658286	(1.114626, 0.983652)	-0.272749	0.235894	0.252853	0.215998
1	0.658437	(1.110584, 0.984280)	-0.273231	0.235942	0.252405	0.215116

Table 4: Optimal recourse policy with $q = q_F^I$

Notably, larger default penalties over initially high protection for borrowers lead to lower mortgage rates and less bank lending. However, since intermediaries provide the earliest, risk-averse depositors with more insurance against liquidity risk, the sum of depositors' expected utilities is higher even though it is evaluated at higher maximum run probabilities for bank run equilibria to exist. Nevertheless, as banks engage in less mortgage market activity, borrowers' welfare is lower which offsets much of the welfare gains by depositors. Yet, aggregate welfare is higher as intermediaries resort to more loan sales and hence investors are able to purchase more mortgages at lower prices to realize higher capital gains in period 2.

By comparison, should the default cost be high enough, the above patterns regarding depos-

itors' and investors' expected utility begin to reverse as banks become more prudent in issuing liabilities to the earliest depositors and sell less loans in the secondary market. While homebuyers' welfare may increase, the magnitude is small. As shown in the table, beyond roughly $\delta = 0.4$, decreasing protections for borrowers would lower welfare at the aggregate level in this economy. Thus, in general, neither a no-recourse policy nor a full-recourse regime is optimal. In addition, this set of results also suggests that providing borrowers with full insurance against negative housing shocks produces higher welfare than forcing them to bear all of the risk.

As robustness checks to the above simulations, we also conduct welfare analysis for cases where q_F^I does not apply under Scenario I. Specifically, we follow the set of parameter values $\left(\pi, \gamma, y^b, \phi, B, q_D, k^c\right) = (0.5, 4, 1.85, 0.7, 1, 2.5\%, 0.2)$ along with $q = q^I$ as in Table 3. However, the behavior of $\mathcal{W}^*$, W^*, W_B^*, and Π^* resembles the results in Table 4 so that they are omitted.

Lastly, to develop further insights into recourse policy, we consider the set of parameters $\left(\pi, \gamma, y^b, \phi, B, q_D, k^c\right) = (0.5, 4, 1.85, 0.7, 1, 2.5\%, 0.2)$ used for Table 3 but with $q = q_F^{II}$. As can be observed from the table below, similar to the previous results, having relatively high protections for borrowers ($\delta = 0.4$) leads to the highest social welfare in the presence of greater potential for run behavior to emerge. Notably, in such a more crisis-prone economy, banks holding excess liquidity supply less mortgage funding at higher costs of default should borrower protection be high. As the penalties for default are higher, the interest rate on loans is lower, decreasing the sum of depositors' welfare but the additional access to mortgages leads to higher expected utility among homebuyers. Meanwhile, outside investors prefer intermediate degrees of borrower protection so that they can purchase loans at lower prices because of a higher level of mortgage sales on the secondary market.

δ	L^{II}	(R^*, p_L^*)	W^*	W_B^*	Π^*	$\mathcal{W}^*$
0	0.439606	(1.262495, 0.877323)	-0.282692	-0.093935	0.280612	-0.096015
.1	0.439545	(1.260339, 0.877008)	-0.282494	-0.094188	0.280951	-0.095731
.2	0.439494	(1.258004, 0.876750)	-0.282331	-0.094421	0.281230	-0.095521
.3	0.439455	(1.255484, 0.876550)	-0.282204	-0.094634	0.281447	-0.095391
.4	0.439430	(1.252755, 0.876417)	-0.282119	-0.094822	0.281594	-0.095347
.5	0.439415	(1.249813, 0.876348)	-0.282076	-0.094986	0.281665	-0.095397
.6	0.439418	(1.246618, 0.876360)	-0.282084	-0.095117	0.281654	-0.095546
.7	0.439436	(1.243159, 0.876454)	-0.282143	-0.095214	0.281551	-0.095807
.8	0.439473	(1.239410, 0.876640)	-0.282261	-0.095273	0.281351	-0.096184
.9	0.439529	(1.235344, 0.876926)	-0.282442	-0.095289	0.281040	-0.096691
1	0.439606	(1.230933, 0.877323)	-0.282692	-0.095257	0.280611	-0.097338

Table 5: Optimal recourse policy with $q = q_F^{II}$

7 Conclusion

In recent years, real-estate related assets have been one of the largest components of the balance sheets of depository institutions in the United States. Yet, during the Global Financial Crisis, housing market activity slumped and record numbers of defaults on mortgages occurred. Some observers blamed protections for mortgage borrowers as a key factor in exacerbating the crisis. Given the important role of banks for extending residential mortgages through maturity transformation, it is important to understand how the legal landscape over mortgage default impacts financial stability. Towards this goal, we build on a version of Diamond and Dybvig (1983) with limited commitment as in Ennis and Keister (2009) and a housing and a mortgage market as in Reed et al. (2018) to study how the vulnerability of intermediaries to a panic depends on mortgage recourse.

It is worth noting that our model allows for the potential for strategic default on loans by mortgage borrowers who are subject to idiosyncratic shocks to the value from homeownership. That is, when homebuyers experience negative housing shocks, it might be better for them to

simply walk away from their mortgage obligations. Under these circumstances, if non-recourse provisions are in place, the cost of strategic default is negligible and mortgage borrowers are fully insured against the loss of the housing value; otherwise, lenders are able to impose larger penalties for default.

In this setup, we show that if borrowers incur lower costs in the event of foreclosure, intermediaries will generally be compensated for default risk with higher interest rates on mortgages. Yet, the banking system is not necessarily less stable at lower penalties for default. In particular, we show by examples that it is possible that the scope for run equilibria where borrowers have full insurance against default is exactly the same as that should full recourse provisions be in place. More importantly, regardless of the probability of a financial crisis, relatively high protections for borrowers are likely to increase the sum of all agents' expected utilities. Nevertheless, in general, neither a no-recourse policy nor a full-recourse regime maximizes aggregate welfare.

8 Technical appendix

Proof of Lemma 1

To begin, it is trivial that $\frac{dL^d}{dR} < 0$ and $\frac{dL^d}{dy^b} > 0$. Next, differentiating L^d with respect to δ and q_D yields:

$$\begin{aligned}
\frac{dL^d}{d\delta} &= \frac{By^b\left(1-q_D\right)}{2R\delta^2}\left(-1-\frac{2\left(1-\phi\right)-\left(\left[\frac{1}{\delta}+\left(1-\phi\right)\right]\left(1-q_D\right)+q_D\right)}{\left[\left(\delta^{-1}\left[1+\delta\left(1-\phi\right)\right]\left(1-q_D\right)+q_D\right)^2-4\delta^{-1}\left(1-q_D\right)\left(1-\phi\right)\right]^{\frac{1}{2}}}\right)<0,\\
\frac{dL^d}{dq_D} &= \frac{By^b}{2\delta R}\left(\left(\delta\phi-1\right)-\frac{\left(\left[1+\delta\left(1-\phi\right)\right]\left(1-q_D\right)+q_D\delta\right)\left(\delta\phi-1\right)+2\delta\left(1-\phi\right)}{\left[\left(\left[1+\delta\left(1-\phi\right)\right]\left(1-q_D\right)+q_D\delta\right)^2-4\delta\left(1-q_D\right)\left(1-\phi\right)\right]^{\frac{1}{2}}}\right)<0.
\end{aligned}$$

■

The bank's best-response allocations

Given that the mortgage rate R and price p_L are taken as given, the best-response allocation of the bank is determined by conditions (11) to (15) and the resource constraints (7) to (10).

Scenario I: $1-L-\pi c_1=0$ and $1-L-\pi c_1<\left(1-\pi\right)\pi c_{1\beta}$

If $q\in\left(0,q^I\right)$, where $q^I=\frac{1}{1+\left(\frac{1-p_L}{\lambda R-1}\right)\left[\pi\left(\frac{\lambda R}{p_L}\right)+\left(1-\pi\right)\left(\frac{\lambda R}{p_L}\right)^{\frac{1}{\gamma}}\right]^{\gamma}}$, the bank does not hold excess liquidity and resorts to loan sales should a run occur, i.e., $\mu_1>0$ and $\mu_{1\beta}=0$. Thus, the vector $c^I=\left\{L^I,c_1^I,c_{2\alpha}^I,c_{1\beta}^I,c_{2\beta}^I\right\}$ is given by:

$$\begin{aligned}
L^I &= 1-\pi c_1^I,\\
c_1^I &= \frac{1}{\pi+\left(1-\pi\right)\left(\left(1-q\right)\left(\lambda R\right)^{1-\gamma}+q\left[\pi+\left(1-\pi\right)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]^{\gamma}p_L^{1-\gamma}\right)^{\frac{1}{\gamma}}},\\
c_{2\alpha}^I &= \frac{\lambda R L^I}{1-\pi},\\
c_{1\beta}^I &= \frac{L^I}{\left(1-\pi\right)\left[\pi+\left(1-\pi\right)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]\left(\frac{1}{p_L}\right)},\\
c_{2\beta}^I &= \frac{\left(\frac{\lambda R}{p_L}\right)^{\frac{1}{\gamma}}L^I}{\left(1-\pi\right)\left[\pi+\left(1-\pi\right)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]\left(\frac{1}{p_L}\right)},
\end{aligned}$$

where $\frac{c_{2\beta}^{I}}{c_{1\beta}^{I}} = \left(\frac{\lambda R}{p_L}\right)^{\frac{1}{\gamma}} > 1$ and $\frac{c_{2\alpha}^{I}}{c_1^{I}} = \left((1-q)\,\lambda R + q\lambda R\left[\pi\left(\frac{\lambda R}{p_L}\right)^{\frac{\gamma-1}{\gamma}} + (1-\pi)\right]^{\gamma}\right)^{\frac{1}{\gamma}} > 1$.

Scenario II: $1 - L - \pi c_1 > 0$ and $1 - L - \pi c_1 < (1-\pi)\,\pi c_{1\beta}$

If $q \in \left[q^{I}, q^{II}\right)$, where $q^{II} = \frac{1}{1+\left(\frac{1-p_L}{\lambda R-1}\right)\left[\pi+(1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1}{\gamma}}\right]^{\gamma}}$, the bank holds excess liquid assets and resorts to loan sales should a run occur, i.e., $\mu_1 = 0$ and $\mu_{1\beta} = 0$. Thus, the vector $c^{II} = \left\{L^{II}, c_1^{II}, c_{2\alpha}^{II}, c_{1\beta}^{II}, c_{2\beta}^{II}\right\}$ is given by:

$$
\begin{aligned}
L^{II} &= \frac{\pi c_1^{II} + (1-q)^{\frac{1}{\gamma}}(1-\pi)\left(\frac{\lambda R-p_L}{1-p_L}\right)^{\frac{1}{\gamma}} c_1^{II} - 1}{\lambda R - 1}, \\
c_1^{II} &= \frac{1}{\pi + (1-q)^{\frac{1}{\gamma}}(1-\pi)\left(\frac{\lambda R-p_L}{1-p_L}\right)^{\frac{1-\gamma}{\gamma}} + q^{\frac{1}{\gamma}}(1-\pi)\left[\pi + (1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]\left(\frac{\lambda R-p_L}{\lambda R-1}\right)^{\frac{1-\gamma}{\gamma}}}, \\
c_{2\alpha}^{II} &= \left(\frac{(1-q)(\lambda R-p_L)}{1-p_L}\right)^{\frac{1}{\gamma}} c_1^{II}, \\
c_{1\beta}^{II} &= \left(\frac{q(\lambda R-p_L)}{\lambda R-1}\right)^{\frac{1}{\gamma}} c_1^{II}, \\
c_{2\beta}^{II} &= \left(\frac{q\lambda R(\lambda R-p_L)}{p_L(\lambda R-1)}\right)^{\frac{1}{\gamma}} c_1^{II},
\end{aligned}
$$

where $\frac{c_{2\beta}^{II}}{c_{1\beta}^{II}} = \left(\frac{\lambda R}{p_L}\right)^{\frac{1}{\gamma}} > 1$ and $\frac{c_{2\alpha}^{II}}{c_1^{II}} = \left(\frac{(1-q)(\lambda R-p_L)}{1-p_L}\right)^{\frac{1}{\gamma}} > 1$.

Scenario III: $1 - L - \pi c_1 > 0$ and $1 - L - \pi c_1 = (1-\pi)\,\pi c_{1\beta}$

If $q \in \left[q^{II}, 1\right)$, the bank holds excess liquid assets but does not resort to costly liquidation should a run occur. First note that $\frac{c_{1\beta}}{c_{2\beta}}$ is determined by:

$$
(1-q)(\lambda R-1)\left[\pi\frac{c_{1\beta}}{c_{2\beta}} + (1-\pi)\right]^{-\gamma} - q\left[\left(\frac{c_{1\beta}}{c_{2\beta}}\right)^{-\gamma} - \lambda R\right] = 0,
$$

where $\frac{c_{2\beta}^{III}}{c_{1\beta}^{III}} > 1$ holds. Then, the vector $c^{III} = \left\{L^{III}, c_1^{III}, c_{2\alpha}^{III}, c_{1\beta}^{III}, c_{2\beta}^{III}\right\}$ is computed by substi-

tuting $\frac{c_{1\beta}^{III}}{c_{2\beta}^{III}}$ along with:

$$\begin{aligned}
L^{III} &= \frac{(1-\pi)^2}{\lambda R} c_{2\beta}^{III}, \\
c_1^{III} &= \left((1-q)\,\lambda R \left[\pi \frac{c_{1\beta}^{III}}{c_{2\beta}^{III}} + (1-\pi) \right]^{-\gamma} + q\lambda R \right)^{-\frac{1}{\gamma}} c_{2\beta}^{III}, \\
c_{2\alpha}^{III} &= \left[\pi \frac{c_{1\beta}^{III}}{c_{2\beta}^{III}} + (1-\pi) \right] c_{2\beta}^{III}, \\
c_{1\beta}^{III} &= \frac{c_{1\beta}^{III}}{c_{2\beta}^{III}} c_{2\beta}^{III}, \\
c_{2\beta}^{III} &= \frac{1}{(1-\pi)\,\pi \frac{c_{1\beta}^{III}}{c_{2\beta}^{III}} + \frac{(1-\pi)^2}{\lambda R} + \pi \left((1-q)\,\lambda R \left[\pi \frac{c_{1\beta}^{III}}{c_{2\beta}^{III}} + (1-\pi) \right]^{-\gamma} + q\lambda R \right)^{-\frac{1}{\gamma}}},
\end{aligned}$$

where $\frac{c_{2\alpha}^{III}}{c_1^{III}} = \left((1-q)\,\lambda R + q\lambda R \left[\pi \frac{c_{1\beta}^{III}}{c_{2\beta}^{III}} + (1-\pi) \right]^{\gamma} \right)^{\frac{1}{\gamma}} > 1$. Yet, as discussed in the main text, $\frac{c_1^{III}}{c_{2\beta}^{III}} < 1$.

■

Proof of Lemma 2

Note that if $q \in \left(0, q^I\right)$, where $q^I = \frac{1}{1+\left(\frac{1-p_L}{\lambda R-1}\right)\left[\pi\left(\frac{\lambda R}{p_L}\right)+(1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1}{\gamma}}\right]^{\gamma}}$, $\mu_1^I > 0$ and $\mu_{1\beta}^I = 0$. That is, the bank does not hold excess liquid assets and resorts to loan sales should a run occur. Yet, if $q \in \left[q^I, 1\right)$, $\pi c_1^{II} < 1 - L^{II}$ and $1 - L^{II} - \pi c_1^{II} < (1-\pi)\,\pi c_{1\beta}^{II}$ hold. In this vein, it would be optimal for the bank to hold excess liquid assets and to resort to loan sales in the panic state.

To proceed, letting $\eta \equiv \lambda R$ denote the expected return to mortgages and differentiating q^I with respect to η gives:

$$\frac{dq^I}{d\eta} = \frac{\frac{1-p_L}{p_L(\eta-1)} \left[\pi \left(\frac{\eta}{p_L} \right) + (1-\pi) \left(\frac{\eta}{p_L} \right)^{\frac{1}{\gamma}} \right]^{\gamma-1} \left(\left(\frac{\eta}{\eta-1} \right) \left[\pi + (1-\pi) \left(\frac{\eta}{p_L} \right)^{\frac{1-\gamma}{\gamma}} \right] - \left[\gamma\pi + (1-\pi) \left(\frac{\eta}{p_L} \right)^{\frac{1-\gamma}{\gamma}} \right] \right)}{\left(1 + \left(\frac{1-p_L}{\eta-1} \right) \left(\frac{\eta}{p_L} \right)^{\gamma} \left[\pi + (1-\pi) \left(\frac{\eta}{p_L} \right)^{\frac{1-\gamma}{\gamma}} \right]^{\gamma} \right)^2}.$$

In particular, $\frac{dq^I}{d\eta} > (<)\, 0$ if $\xi_1^I > (<)\, \xi_2^I$ where $\xi_1^I = \eta\pi$ and $\xi_2^I = (\eta-1)\,\gamma\pi - (1-\pi)\left(\frac{\eta}{p_L}\right)^{\frac{1-\gamma}{\gamma}}$. Note that $\lim_{\eta\to 1} \xi_1^I = \pi > \lim_{\eta\to 1} \xi_2^I = -(1-\pi)\left(\frac{1}{p_L}\right)^{\frac{1-\gamma}{\gamma}}$ and $\lim_{\eta\to\infty} \xi_1^I < \lim_{\eta\to\infty} \xi_2^I$. Note also that $\frac{d\xi_1^I}{d\eta} =$

$\pi > 0$, $\frac{d\xi_2^I}{d\eta} = \gamma\pi + (1-\pi)\left(\frac{\gamma-1}{\gamma}\right)\left(\frac{\eta}{p_L}\right)^{\frac{1-2\gamma}{\gamma}}\frac{1}{p_L} > 0$, and $\frac{d\xi_2^I}{d^2\eta} = (1-\pi)\left(\frac{(\gamma-1)(1-2\gamma)}{(p_L\gamma)^2}\right)\left(\frac{\eta}{p_L}\right)^{\frac{1-3\gamma}{\gamma}} <$ 0. Thus, there exists a unique $\eta^I > 1$ such that $\frac{dq^I}{d\eta} > (<)\,0$ if $\eta < (>)\,\eta^I$.

Lastly, the derivative $\frac{dq^I}{dp_L} > 0$ is as follows:

$$\frac{dq^I}{dp_L} = \frac{\left[\pi\left(\frac{\lambda R}{p_L}\right) + (1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1}{\gamma}}\right]^{\gamma-1}\left(\frac{\lambda R}{(\lambda R-1)p_L}\left[\pi + (1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right] + \frac{(1-p_L)\lambda R}{\lambda R-1}\left(\frac{\gamma\pi}{p_L^2} + \frac{(1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}}{p_L^2}\right)\right)}{\left(1 + \left(\frac{1-p_L}{\lambda R-1}\right)\left[\pi\left(\frac{\lambda R}{p_L}\right) + (1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1}{\gamma}}\right]^{\gamma}\right)^2}$$

■

Proof of Lemma 3

i. Differentiating L^I with respect to R, q, and λ yields $\frac{dL^I}{dR} < 0$, $\frac{dL^I}{dq} > 0$, and $\frac{dL^I}{d\lambda} < 0$:

$$\frac{dL^I}{dR} = \frac{\frac{\pi(1-\pi)(1-\gamma)}{\gamma}\left((1-q)(\lambda R)^{1-\gamma} + q\left[\pi + (1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]^{\gamma}p_L^{1-\gamma}\right)^{\frac{1-\gamma}{\gamma}}\left(\frac{(1-q)\lambda}{(\lambda R)^{\gamma}} + qp_L^{1-\gamma}\left[\pi + (1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]^{\gamma-1}(1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-2\gamma}{\gamma}}\frac{\lambda}{p_L}\right)}{\left[\pi + (1-\pi)\left((1-q)(\lambda R)^{1-\gamma} + q\left[\pi + (1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]^{\gamma}p_L^{1-\gamma}\right)^{\frac{1}{\gamma}}\right]^2},$$

$$\frac{dL^I}{dq} = \frac{\frac{\pi(1-\pi)}{\gamma}\left((1-q)(\lambda R)^{1-\gamma} + q\left[\pi + (1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]^{\gamma}p_L^{1-\gamma}\right)^{\frac{1-\gamma}{\gamma}}\left(-(\lambda R)^{1-\gamma} + \left[\pi + (1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]^{\gamma}p_L^{1-\gamma}\right)}{\left[\pi + (1-\pi)\left((1-q)(\lambda R)^{1-\gamma} + q\left[\pi + (1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]^{\gamma}p_L^{1-\gamma}\right)^{\frac{1}{\gamma}}\right]^2},$$

$$\frac{dL^I}{d\lambda} = \frac{\frac{\pi(1-\pi)(1-\gamma)}{\gamma}\left((1-q)(\lambda R)^{1-\gamma} + q\left[\pi + (1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]^{\gamma}p_L^{1-\gamma}\right)^{\frac{1-\gamma}{\gamma}}\left(\frac{(1-q)R}{(\lambda R)^{\gamma}} + qp_L^{1-\gamma}\left[\pi + (1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]^{\gamma-1}(1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-2\gamma}{\gamma}}\frac{R}{p_L}\right)}{\left[\pi + (1-\pi)\left((1-q)(\lambda R)^{1-\gamma} + q\left[\pi + (1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]^{\gamma}p_L^{1-\gamma}\right)^{\frac{1}{\gamma}}\right]^2},$$

where $\frac{d\lambda}{d\delta} = q_D > 0$ and $\frac{d\lambda}{dq_D} = \delta - 1 < 0$, implying that $\frac{dL^I}{d\delta} < 0$ and $\frac{dL^I}{dq_D} > 0$.

ii. To proceed, first differentiating c_1^{II} with respect to q yields:

$$\frac{dc_1^{II}}{dq} = \frac{\left(\frac{1-\pi}{\gamma}\right)\left[\left(\frac{\lambda R-p_L}{1-p_L}\right)^{\frac{1-\gamma}{\gamma}}(1-q)^{\frac{1-\gamma}{\gamma}} - \left[\pi + (1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]\left(\frac{\lambda R-p_L}{\lambda R-1}\right)^{\frac{1-\gamma}{\gamma}}q^{\frac{1-\gamma}{\gamma}}\right]}{\left(\pi + (1-q)^{\frac{1}{\gamma}}(1-\pi)\left(\frac{\lambda R-p_L}{1-p_L}\right)^{\frac{1-\gamma}{\gamma}} + q^{\frac{1}{\gamma}}(1-\pi)\left[\pi + (1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]\left(\frac{\lambda R-p_L}{\lambda R-1}\right)^{\frac{1-\gamma}{\gamma}}\right)^2}.$$

That is, $\frac{dc_1^{II}}{dq} < 0$ if and only if $q < \frac{1}{\left(\frac{1-p_L}{\lambda R-1}\right)\left[\pi+(1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]^{\frac{\gamma}{1-\gamma}}+1} = \bar{q}^{II}$. Notably, as we will demonstrate in the proof of Proposition 4 below, the fragility condition $c_1^{II} \geq c_{2\beta}^{II}$ holds if $q \leq q_F^{II} \equiv \frac{p_L(\lambda R-1)}{\lambda R(\lambda R-p_L)}$ and it can be shown that $\bar{q}^{II} > q_F^{II}$. In turn, conditional on the existence of run equilibria where the allocation c^{II} is implemented, $\frac{dc_1^{II}}{dq} < 0$. In this vein,

$$\frac{dL^{II}}{dq} = \frac{\pi\frac{dc_1^{II}}{dq} + (1-\pi)\left(\frac{\lambda R-p_L}{1-p_L}\right)^{\frac{1}{\gamma}}\left[-\frac{1}{\gamma}(1-q)^{\frac{1}{\gamma}-1}c_1^{II} + (1-q)^{\frac{1}{\gamma}}\frac{dc_1^{II}}{dq}\right]}{\lambda R-1} < 0.$$

Combining the results that $\frac{dL^{II}}{dq} < 0$ and $\frac{dq^I}{d\eta} > (<)\,0$ if $\eta < (>)\,\eta^I$, there exist thresholds R^I, δ^I, and q_D^I such that $\frac{dL^{II}}{dR} > (<)\,0\ \forall R < (>)\,R^I$, $\frac{dL^{II}}{d\delta} > (<)\,0\ \forall \delta < (>)\,\delta^I$, and $\frac{dL^{II}}{dq_D} < (>)\,0$ $\forall q_D > (<)\,q_D^I$.

■

Proof of Proposition 1

To demonstrate conditions under which the mortgage market equilibrium exists and is unique, note that under Scenario I, the equilibrium mortgage rate R^* is determined such that $L^d = L^I$. Multiplying both sides by R gives $RL^d = RL^I$, where RL^d is now independent of R. In this vein, R^* is shown to exist and to be uniquely determined if the curve RL^I intersects the vertical line RL^d once. Importantly, as $\left(\frac{\lambda R}{p_L}\right)^2 > \frac{\gamma-1}{\gamma}$, it can be proved that RL^I is strictly increasing in R:

$$\frac{d\left(RL^I\right)}{dR} = \frac{\left((1-q)(\lambda R)^{1-\gamma} + q\left[\pi+(1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]^{\gamma}p_L^{1-\gamma}\right)^{\frac{1}{\gamma}-1}(1-\pi)\,\psi}{\left(\pi+(1-\pi)\left((1-q)(\lambda R)^{1-\gamma} + q\left[\pi+(1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]^{\gamma}p_L^{1-\gamma}\right)^{\frac{1}{\gamma}}\right)^2},$$

where

$$\begin{aligned}
\psi \;=\; & \left(\frac{\pi}{\gamma}\right)(1-q)(\lambda R)^{1-\gamma} \\
& + qp_L^{1-\gamma}\pi\left[\pi+(1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]^{\gamma-1}\left(\pi+(1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1}{\gamma}-3}\left[\left(\frac{\lambda R}{p_L}\right)^2+\frac{1-\gamma}{\gamma}\right]\right) \\
& + (1-\pi)\left((1-q)(\lambda R)^{1-\gamma} + qp_L^{1-\gamma}\left[\pi+(1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]^{\gamma}\right) \\
& \times\left((1-q)(\lambda R)^{1-\gamma} + qp_L^{1-\gamma}\left[\pi+(1-\pi)\left(\frac{\lambda R}{p_L}\right)^{\frac{1-\gamma}{\gamma}}\right]^{\gamma}\right)^{\frac{1}{\gamma}}.
\end{aligned}$$

Given that $\lim_{R\to\infty} RL^I >> RL^d$, the existence and uniqueness of mortgage market equilibria are established if $\lim_{R\to\frac{1}{\lambda}} RL^I < RL^d$. In particular, $\lim_{R\to\frac{1}{\lambda}} RL^I < RL^d$ if $y^b > \underline{y}^I = \frac{1-\pi}{B(1-q_D)(1-\phi)}$ for $\delta = 0, 1$ or $y^b > \underline{y}^I = \frac{2\delta(1-\pi)}{B\lambda\left([1+\delta(1-\phi)](1-q_D)+q_D\delta-\left(([1+\delta(1-\phi)](1-q_D)+q_D\delta)^2-4\delta(1-q_D)(1-\phi)\right)^{\frac{1}{2}}\right)}$ for $\delta \in (0,1)$.

Next, conditional on the existence of equilibria under Scenario I, the same lower bound on a homebuyer's income $\underline{y}^I$ also applies under Scenario II. In this vein, if $y^b \in \left(\underline{y}^I, \bar{y}^{II}\right)$, where $\bar{y}^{II} : R^* = R^I$, the mortgage market equilibrium exists and is unique.

■

Proof of Proposition 2

To begin, suppose that $y^b > \underline{y}^I$ under Scenario I and $y^b \in \left(\underline{y}^I, \bar{y}^{II}\right)$ under Scenario II. Under these conditions, by $R^* : L^d = L^*$, $\frac{dL^d}{dq} = 0$, $\frac{dL^I}{dq} > 0$, and $\frac{dL^{II}}{dq} < 0$, as demonstrated in the proof of Lemmas 1 and 3, $\frac{dR^*}{dq} < (>)\, 0$ under Scenario I (II).

Next, we prove that $\frac{dR^*}{d\delta} < 0$. To establish this result, first note that derivatives $\frac{dL^d}{d\delta}$ and $\frac{dL^I}{d\delta}$ are strictly decreasing in and independent of y^b, respectively. Further, suppose that y^b goes to the minimum value $\underline{y}^I$ such that $R^* = \frac{1}{\lambda}$. Under this condition, $\frac{dL^d}{d\delta} < \frac{dL^I}{d\delta} = 0$. In this vein, for any $y^b > \underline{y}^I$, $\frac{dL^d}{d\delta} < \frac{dL^I}{d\delta} < 0$, implying that $\frac{dR^*}{d\delta} < 0$ under Scenario I. In addition, by $\frac{dL^d}{d\delta} < 0$ and $\frac{dL^{II}}{d\delta} > 0$, then $\frac{dR^*}{d\delta} < 0$ under Scenario II as well.

Lastly, it is trivial to show that $\frac{dR^*}{dy^b} > 0$.

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