Open Banking with Depositor Monitoring

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Abstract

Open banking is a policy innovation that allows borrowers to share their data with any financial institution in lending markets. This paper studies how open banking reshapes lending market competition and whether it will increase borrower welfare or optimize resource allocations. We develop a model of banking competition with bank depositors responding to bank investments endogenously. Depositors' monitoring exacerbates winner's curse, which can result in informational monopoly under current banking and make banks hesitate to fund borrowers under open banking. Relative to the current banking system, open banking can lead to higher borrower welfare but inefficient resource allocations, lowering ex-ante economic efficiency.

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Open banking, or consumer-directed finance, is a major policy innovation that aims to reshape lending market competition and increase consumer welfare. It allows third-party financial service providers to access consumer banking, transactions, and other financial data from banks and non-bank financial institutions. Hence, under an open banking system, consumers are able to direct their financial institutions to share certain types of their personal information with service providers they choose. As a result, banking competition increases, and consumers should be able to enjoy lower financing costs and better financial services.

While open banking's potential benefits to consumers have encouraged the UK, Australia, and some other European countries to switch to such a new regime, it has not been fully accepted by the U.S. and other developed countries.[1] One reason for the hesitation of adopting open banking is that we know too little about whether and how open banking will impact financial system health and stability. In this paper, we propose a formal framework to study such an open question.

Following Admati (2019), we regard a financial system as healthy and stable if it can enable efficient resource allocation. This involves the financial system's *funding efficiency* and its *screening efficiency*, which respectively refer to serving high credit-quality borrowers and screening low credit-quality ones. We show that open banking outperforms current banking in funding efficiency when the conditional (on success) project return is high and in screening efficiency when the conditional project return is low. On average, however, open banking underperforms current banking in allocating resources, implying its adverse impact on the financial system's health and stability.

We develop a model with two banks (bank 1 and bank 2) competing for one borrower. The borrower's creditworthiness may be high or low.[2] If funded, a high credit-quality borrower will generate a positive cash flow (which is the conditional project return), while a low-type borrower will default. The borrower's credit quality is unknown to any agent, and to emphasize the resource-allocation role of the banking system, we

[1] In the U.S., President Biden just signed an executive order on July 9, 2021, to give the green light for US open banking, and the next-step in substantive rulemaking should be expected by March 2022. In Canada, the government is soliciting opinions about benefits and risks of an open banking system. One major concern of adopting open banking, as Bank of Canada states, is "how risks related to consumer protection, privacy, cyber security and **financial stability** should be managed."

[2] Banks' risks associated with the borrower's credit quality can also be viewed as the systematic risk of issuing loans to a specific group of borrowers. This is related to banking specialization. We shall explain more details when we describe the model and formally argue in the appendix that our results hold if we consider a systematic risk of lending to a specific group of investors.

assume that it is inefficient to fund the borrower ex ante. The two banks compete in a sealed-bid first-price common-value auction setting. In particular, the bank that bids the lower interest rate will fund the borrower, while the bank that loses the competition will invest in a risk-free project and get its reservation value.

Bank 1 is the borrower's home bank, which possesses the historical data about the borrower's consumption, finance, and investment. Based on these data, bank 1 generates a private signal about the borrower's credit quality by its own algorithm. Under the current banking system, bank 2 cannot access the borrower's data and so has no information about the borrower's credit quality. Under an open banking system, however, bank 2 can access the borrower's data and then use its own algorithm to generate a signal about the borrower's credit quality, which is conditionally independent of and identically distributed as bank 1's signal.

The most important feature of our model is that bank depositors endogenously respond to bank investments. This arises from the maturity mismatch in the bank industry, which suggests that bank depositors get chances to renegotiate a new interest rate when banks roll over deposits. Such an assumption is also supported by empirical evidence that uninsured deposit flows are sensitive to information about bank investment (Chen et al., 2021a,b). In our model, each bank finances from a competitive depositor, who is not covered by deposit insurances. When a depositor finds that his bank wins the competition (together with the winning bid), he updates his belief about the borrower's credit quality and requires a new deposit interest rate. The depositor's response to his bank's investment affects the winning bank's expected payoff, and so when banks bid, they rationally take their depositors' responses into account.

We first characterize the banking industry organization under both banking systems. Under current banking, there is a unique equilibrium that is in pure strategy and satisfies the intuitive criterion.[3] In equilibrium, the depositors' monitoring prevents bank 2 from participating in the competition and makes the borrower's home bank (bank 1) an informational monopolist. Intuitively, if bank 2 bids and wins, the most optimistic scenario it can have is winning the competition for sure; otherwise, bank 2 suffers a winner's curse, which means that bank 2's winning suggests that bank 1 is likely to observe a bad signal about the borrower's credit quality. Even in such most optimistic scenario, bank 2's conditional (on winning) payoff will be strictly lower than its reservation value

[3]The reason why we apply intuitive criterion test to refine the equilibrium set is the potential signaling effect of the winning bank's bid about its own private signal.

from investing in the risk-free project. This arises from the fact that bank 2 does not possess any new information, and its depositor would require a much higher deposit interest rate to compensate the risk he is taking. Therefore, bank 2 will not participate in the competition, and bank 1 becomes a monopolist due to its information advantage and always funds the borrower if receiving a good signal.

We notice that bank 2's depositor's response plays an important role in making bank 1 an informational monopolist. In particular, bank 2's depositor monitors its investment and makes it more conservative. With the assumption that bank depositors do not respond to bank investments, we show that bank 2, albeit uninformed, may fund the borrower with strictly positive probability in equilibrium. Such an equilibrium is in mixed strategy and is similar to those characterized in the literature on lending market competition with asymmetrically informed creditors (Hauswald and Marquez, 2003; He et al., 2021).

Differing from current banking, under open banking, bank 2 can generate a private signal that has the same quality as bank 1's signal. This is because in our model, the borrower can freely share her own data to shop rates.[4] We characterize a unique symmetric equilibrium that satisfies the intuitive criterion. In equilibrium, a bank with a good signal refrains from bidding with strictly positive probability. As a result, when a bank observes a good signal, its equilibrium expected payoff equals its reservation value.

The equilibrium property under open banking arises from the exacerbated winner's curse caused by depositors' responses. To see the intuition, we suppose that banks surely bid when receiving good signals. Consider the case that bank i bids the conditional project return and wins the competition.[5] Since banks do not bid any particular rate with strictly positive probability, bank i's winning implies that bank j observes a bad signal, which neutralizes bank i's good signal. This is the winner's curse highlighted in the literature on common-value auctions. What is special in our model is that bank i's depositor understands the winner's curse and thus requests a much higher deposit interest rate (than in the case where bank i is a monopolist). Hence, bank i's financial cost increases, and its expected payoff will be lower than its reservation value. Therefore, in

[4]We abstract away the incentive problem of rate shopping so that we can focus on the effects of bank depositors' endogenous responses.

[5]The conditional project return is the highest possible amount a bank may bid in equilibrium, since an even higher bid will never be accepted by the borrower. We also show that in an equilibrium that satisfies the intuitive criterion, the upper bound of a bank's strategy support must be the conditional project return.

equilibrium, bank j must refrain from bidding with strictly positive probability, so that the winner's curse to bank i is alleviated, and bank i, by bidding the conditional project return, receives a conditional payoff equal to its reservation value.

To further demonstrate the role of depositors' responses in determining the banking competition under the open banking system, we also solve a model where bank depositors do not respond to bank investments. We show that without depositors' monitoring, in equilibrium, both banks bid for sure when they observe good signals. In addition, both banks' equilibrium payoffs are strictly positive. This is indeed a special case with only two banks in Broecker (1990).

With the characterizations of the banking competition under current banking and under open banking, we study whether the open banking system is healthier than the current banking system. We first analyze the banking system's funding efficiency, which is measured by the probability of a high credit-quality borrower getting funded. Under current banking, bank 2 never bids, and bank 1 lends to the borrower if and only if it observes a good signal about the borrower's credit quality. Hence, the current banking's funding efficiency equals the probability of bank 1 receiving a good signal. Under open banking, on the other hand, although the borrower can potentially finance from two banks, each bank refrains from lending to the borrower with strictly positive probability. We show that when the conditional project return is low, no bank lends to the borrower with significantly positive probability, and so the open banking system underperforms the current banking system in funding efficiency. On the other extreme, when the conditional project return is high, both banks bid almost surely, and so the open banking system outperforms the current banking system in funding efficiency.

The screening efficiency is just the opposite because a financial system is more efficient in screening if it funds low credit-quality borrowers with lower probability. Similarly to the discussion of the funding efficiency, when the conditional project return is low, the open banking system is less likely to fund low credit-quality borrowers and so outperforms the current banking system. On the other hand, when the conditional project return is high, the open banking system is more likely to fund low credit-quality borrowers and so underperforms the current banking system.

For both funding efficiency and screening efficiency, the depositors' responses play a critical role in comparing open banking with current banking. Specifically, under open banking, the probability of a bank with a good signal refraining from bidding decreases in the conditional project return. When the conditional project return is low, the depositors' responses have strong monitoring effects on bank investments, since the resulting bank financial costs will severely exacerbate the winner's curse; hence banks behave extremely conservatively. As the conditional project return increases, winning the competition by bidding the conditional project return brings a bank a higher expected payoff, without affecting the winner's curse and its depositor's response. So, the probability of the other bank refraining from bidding decreases to keep the first bank's conditional payoff equal to its reservation value.

The ex-ante economic efficiency of a banking system is then the average of its funding efficiency and its screening efficiency, taking into account the economic gain from a high credit-quality borrower and the economic loss from a low credit-quality borrower.[6] We show that for any potential project return in the range that we focus on, open banking unfortunately underperforms current banking. Such a result suggests that with bank depositors' endogenous responses to bank investments, in a non-trivial and plausible range of conditional project returns, informational monopoly may be natural monopoly, which leads to higher economic efficiency than competition. This result also echos the concern of the central banks of several developed countries: Allowing borrowers to freely share their data with third-party financial institutions may adversely impact the financial system's health and stability.

Our study also sheds light on which banking system can better serve borrowers, another important aspect discussed in policy circles about switching from current banking to open banking. In equilibrium, under the current banking system, the borrower's home bank offers a monopoly price, extracting all borrower surplus. Therefore, a high credit-quality borrower, even if funded, will get a zero payoff ex post. By contrast, under the open banking system, the high credit-quality borrower can get a positive expected payoff, since competition will drive down the interest rates the banks charge. Therefore, open banking does improve borrower's welfare.

Our paper is among the first ones that study open banking theoretically. In a recent working paper, He et al. (2021) highlight borrowers' endogenous sign-up decisions to the open banking program and show that open banking could make the entire financial industry better off but leave all borrowers worse off. Parlour et al. (2021) consider Fin-

[6]In the analysis of economic efficiency, we assume that under open banking, all agents plays the unique symmetric equilibrium that satisfies the intuitive criterion. We also characterize all asymmetric equilibria that satisfy the intuitive criterion, and surprisingly find that the ex-ante economic efficiency is constant across all equilibria. Hence, the equilibrium selection does not matter for the comparison between open banking and current banking in terms of ex-ante economic efficiency.

Tech companies' competition in the payment market, and the payment data are owned and can be ported by consumers, which affects the loan contracts offered by a monopoly bank. They show that there is unraveling in equilibrium, and so the option to port data means all consumers will port data. While we think that borrowers' endogenous data-sharing decisions are an important and interesting feature of open banking, we abstract them away. Instead, we emphasize bank depositors' endogenous responses to bank investments, which is an inherent feature of any financial intermediaries. Because of the different focuses, we get distinct results. In particular, we show that relative to current banking, open banking makes high credit-quality borrowers strictly better off but leads to inefficient resource allocation ex ante, and so it may not be a healthier banking system.

More generally, our paper contributes to the literature on lending market competition. Our model of open banking is similar to that developed by Broecker (1990), except the depositors' endogenous responses to bank investments. Without bank depositors' monitoring, Broecker (1990) shows that when there are only two banks, both banks, when observing good signals, will bid for sure, and when there are sufficiently many banks, banks may choose not to bid even if they observe good signals. The latter result is similar to ours but arises from different reasons: In Broecker (1990), a large number of losing banks is an extremely bad signal to the winning bank, causing a severe winner's curse, while in our model, the winner's curse to the bank is moderate, but the depositor's response exacerbates it.

On the other hand, our model of current banking is similar to Hauswald and Marquez (2003). Hauswald and Marquez (2003) abstract away bank depositors' monitoring and focus on the case where it is ex-ante efficient to fund the borrower. They prove that with asymmetrically informed banks, the unique equilibrium is in mixed strategy, and the uninformed bank will participate in the competition. By contrast, with the depositors' responses, we show that if it is ex-ante inefficient to fund the borrower, the unique equilibrium is in pure strategy in which the uninformed bank will never bid and the informed bank is an informational monopoly.

1 A Model of Banking Competition

We consider an economy with two creditors competing for one borrower. While we call the creditors "banks" for simplicity, they could be other financial intermediaries in the lending market, such as credit unions, trust companies, and fintech companies. The economy lasts for three days, indexed by $t = 1, 2, 3$.

The Borrower At the beginning of day 1, the borrower needs to finance \$1 for her small business, and the banks are the only financing source.[7] The small business will generate a random cash flow x at day 3. Specifically,

$$x = \begin{cases} R > 1, & \text{with probability } \theta; \\ 0, & \text{with probability } 1 - \theta. \end{cases} \tag{1}$$

Here, $\theta \in \{L, H\}$ indicates the borrower's credit quality. We call a high credit quality borrower an "H-borrower" and a low credit quality borrower an "L-borrower."

Without losing any generality, we assume that $L = 0$ and $H = 1$; that is, an L-borrower can never generate a positive cash flow at day 3, while an H-borrower will surely get a cash flow R at day 3 if she is funded by a bank. Since the borrower tries to borrow \$1 at day 1, R can be interpreted as both an amount or a gross return. If the small business cannot generate a cash flow at day 3, the borrower will default with a zero liquidation value; in such a case, she makes no repayment because of her limited liability. By contrast, if the small business generates the cash flow R at day 3, the borrower will pay the bank back as she promises. We therefore call R the conditional (on no default) project return.

We assume that all agents in our model share an equal common prior about the borrower's credit quality; that is, $\Pr(\theta = H) = 1/2$. For simplicity, we assume that the borrower does not know her credit quality so that the borrower's behavior does not reveal any information about her credit quality.

While we consider one "big" borrower in our model, the risk of issuing a loan to her can be viewed as the systematic risk of lending a group of borrowers. When there is a continuum of borrowers, banks can potentially hold well-diversified portfolios that contain systematic risks only. This is indeed related to banking specialization (Carey et al., 1998; Daniels and Ramirez, 2008; Paravisini et al., 2015; De Jonghe et al., 2020; Giometti and Pietrosanti, 2020). In Appendix B, we formally present a model with a continuum of borrowers who are subject to a systematic shock. We argue there that with some plausible assumptions about banks' information about the systematic shock, our results still hold.

[7] The borrower may also finance for her current consumption. In this case, the borrower will use her salary at day 3 to pay back the loan, and due to the uncertainty of unemployment, her salary at day 3 has the same structure as described in equation (1).

Banks Both banks can serve the borrower in our model. They are, however, heterogeneous in the information about the borrower's credit quality θ. In particular, bank 1 is the borrower's home bank, who can access to the borrower's historical transaction data. Based on those data, bank 1 generates a private signal s_1 about the borrower's credit quality by its own screening algorithm. Specifically, we assume that

$$\Pr(s_1 = \theta|\theta) = \pi \in (1/2, 1), \ \forall\, \theta \in \{L, H\}. \tag{2}$$

Here, π is bank 1's signal precision and so measures the efficiency of bank 1' screening technology. We assume that under current banking, bank 2 cannot view the borrower's transaction data; hence, it does not observe any new signal beyond the prior.

At day 1, each bank chooses between funding the borrower or investing the \$1 in a risk-free project. Suppose that the risk-free project will generate a cash flow $R_a \in (0, R)$. We shall focus on the case that[8]

$$R \in \left(\frac{R_a}{\pi}, 2R_a\right). \tag{3}$$

On the one hand, $R < 2R_a$ implies that without any new information, it is inefficient to fund the borrower. By this assumption, banks play an important role in resource allocation because of their information generation algorithms. On the other hand, $R > R_a/\pi$ suggests that if there is at least one good signal about the borrower's credit quality, it is efficient to fund her.

Banking Competition At day 1, both banks simultaneously make offers to the borrower based on their own signals. They may also refrain from making an offer. Denote by $b_i \in [1, R]$ the gross rate quoted by bank i and by $b_i = \infty$ bank i's choice of not making an offer. Observing the quotes from both banks, the borrower chooses bank i if $b_i < b_j$. In a tie case $b_i = b_j < \infty$, the borrower chooses bank i with probability $1/2$, and if and only if $b_i = b_j = \infty$, the borrower is not funded. We denote by $\hat{b}$ the winning bid and by ι the identity of the winning bank; obviously, $\hat{b} \in [1, R]$. Once the borrower is funded, ι

[8] We analyze the case where $R \geq 2R_a$ in Appendix C. In such a case, bank depositors' monitoring does not play a critical role. We, however, find that when the conditional project return R is sufficiently large, open banking will reduce borrower welfare. The new economic insight there is that when R is large, banks with bad signals may mimic banks with good signals and bid. To prevent such mimicking behavior, banks with good signals cannot bid too high. Indeed, the equilibrium bids of banks with good signals are much lower under current banking than under open banking, because of the winner's curse under open banking. As a result, when R is sufficiently large, borrower welfare is lower under open banking.

and $\hat{b}$ will be revealed to bank ι's depositor. The losing bank will invest in the alternative project, and its quote is never revealed to any agent except the borrower.

The banks compete in a sealed-bid first-price common-value auction. However, as we describe below, our model differs from classic common-value auctions mainly in bank depositors' responses to the winning bid. If bank ι wins the competition, its winning bid is revealed to its depositor, who will then renegotiate the deposit interest rate with bank ι. The signaling effect of the winning bid (about the winning bank's private signal) and the potential winner's curse in the common-value auction will then impact the winning bank's depositor's belief and thus the winning bank's financial cost. Intuitively, such a renegotiation will result in a higher interest rate because of the credit risk. The banks take such a renegotiation into account when making offers to the borrower.

Banks' Financial Costs Each bank finances its \$1 from a competitive depositor with a promised gross return $r \in (1, R)$ at day 3. The depositors are not covered by FDIC deposit insurance, and the banks have also limited liabilities. So the banks will pay their depositors up to r at day 3 if they can. Obviously, if a bank gets a zero cash flow at day 3, its depositor will get a zero payment.

The most important feature of our model is that the promised gross return r is endogenous. In particular, at day 2, each bank's depositor can observe whether his bank is lending to the borrower or investing in the risk-free project. If a bank invests in the risk-free project, the bank promises to pay its depositor a gross rate $r_a \in (1, R_a)$, which is exogenously given. (We may view r_a as the status quo, and only when the bank changes its investment, it needs to renegotiate with the depositor.) Hence, by investing in the risk-free project, the bank's payoff will be $R_a - r_a > 0$. After bank ι funds the borrower, on the other hand, its depositor forms a posterior ζ about the borrower's credit quality based on his bank's quote to the borrower. Because the depositor is competitive, the winning bank will then adjust its promised deposit interest rate to $r = r_a/\zeta$ to avoid any withdrawal and investment liquidation.

Open banking The economy with an open banking system is the same as that with the current banking system, except that the borrower possesses the data of the transactions he made with bank 1. We assume that under the open banking system, the depositor will share with bank 2 his transaction data to shop interest rates. Bank 2 will then use its own algorithm to generate a signal s_2, which is conditionally independent of s_1. In particular, bank 2's signal has the same precision as bank 1's signal

$$\Pr(s_2 = \theta|\theta) = \pi, \; \forall\, \theta \in \{L, H\}. \tag{4}$$

The assumption that the borrower will surely shop the rate under open banking largely simplifies our analysis, since the borrower's rate shopping behavior is not informative about her credit quality.

Equilibrium Each bank i's bidding strategy $\beta_i : \mathcal{I}_i \to [1, R] \cup \{\infty\}$, and a belief system $\zeta(\hat{b}, \iota)$ for all $\hat{b} \in [1, R]$ and $\iota \in \{1, 2\}$ constitute a monotone equilibrium if

1. given the belief system ζ, each bank's bidding strategy is decreasing in its private signal and maximizes its own payoff; and
2. the belief system $\zeta(\hat{b}, \iota)$ is decreasing in $\hat{b}$ and is consistent with the banks' bidding strategies.

When there are multiple equilibria due to off-equilibrium path beliefs, we apply the *intuitive criterion* to refine the equilibrium set.

2 Current Banking System

In this section, we study banking competition under current banking, where bank 2 does not have any information about the borrower's credit quality. We shall show that for any return of the small business that satisfies equation (3), the borrower will be funded by the home bank if it observes a good signal. However, by funding the borrower, the home bank will extract all borrower surplus.

We start our analysis of banking competition under current banking with bank 2's equilibrium bidding strategy. Lemma 1 shows that bank 2 never participates in the competition.

Lemma 1. *Under current banking, for any $R \in \left(\frac{R_a}{\pi}, 2R_a\right)$, bank 2's bidding strategy is $\beta_2 = \infty$ in equilibrium.*

The fact that bank 2 does not participate in the competition arises from its depositor's response to its investment, which exacerbates the winner's curse if it wins the competition. Suppose that bank 2 bids and wins. Its depositor will then evaluate the risk of his deposit. Intuitively, the most optimistic posterior bank 2's depositor can have is when bank 2's bid wins the competition for sure. (Bank 1 bids only when it receives a good signal, so if bank 1 wins with strictly positive probability in equilibrium, bank 2's winning will make its depositor think bank 1 is likely to observe a bad signal and thus become even more pessimistic.) Since bank 2 does not have any private information about the borrower's credit quality, the most optimistic posterior belief its depositor can have is $\Pr(\theta = H|\iota = 2) = 1/2$. He will then request a new interest rate $2r_a$, which will be bank 2's lowest possible financial cost if it funds the borrower. As a result, bank 2's expected payoff from funding the borrower is at most $\frac{1}{2}(R - 2r_a) < R_a - r_a$ for any $R \in (R_a/\pi, 2R_a)$, implying that bank 2 never bids in equilibrium.

On the other hand, bank 1's quote is informative about its private signal. To simplify the analysis, we assume that the home bank's private signal is sufficiently precise; that is, in the rest of the paper, we will maintain the parameter assumption in equation (5):

$$\pi \geq \frac{r_a}{R_a}. \tag{5}$$

With such an assumption, bank 1 does not make an offer to the borrower if it observes a bad signal, even if it is perceived to receive a good signal.

We then characterize the unique equilibrium that satisfies intuitive criterion under current banking.

Proposition 1. *For any $R \in (R_a/\pi, 2R_a)$, there is a unique equilibrium that satisfies intuitive criterion, in which bank 1's bidding strategy is*

$$\beta_1^c(s_1) = \begin{cases} \infty, & \text{if } s_1 = L; \\ R, & \text{if } s_1 = H, \end{cases} \tag{6}$$

and the belief of bank 1's depositor when bank 1 funds the borrower is

$$\zeta(\hat{b}, \iota = 1) = \pi, \ \forall\, \hat{b} \in (1, R]\,. \tag{7}$$

Proposition 1 shows that our model differs from classic first-price common-value auctions with asymmetric bidders, and in particular, their applications in lending market competitions, such as Hauswald and Marquez (2003) and He et al. (2021). In particular, the unique equilibrium under current banking is a pure-strategy equilibrium in which bank 2 does not participate in the competition. Importantly, such a result is independent of bank 1's signal precision: Even if bank 1's private signal is very imprecise, that is, π is very close to $1/2$ and equation (5) is violated, bank 2 will not make an offer to the borrower. This is due to the severe winner's curse caused by bank 2's depositor's response to funding the borrower. Indeed, in Section 4, we show that if banks' financial costs are exogenously fixed at r_a, there exists a unique equilibrium in which bank 1 randomizes over $[R_a/\pi, R]$ with a positive mass on R and bank 2 randomizes over $[R_a/\pi, R) \cup \{\infty\}$ with a positive mass on ∞. Such an equilibrium is similar to those characterized in the literature.

We are now at a position to study the current banking system's funding efficiency, its screening efficiency, and its ex-ante economic efficiency. In the equilibrium characterized in Proposition 1, bank 1 always funds the borrower if it receives a good signal, and it will not lend to the borrower if it receives a bad signal. In addition, the current banking system's funding efficiency and screening efficiency are both independent of the project return R. The current banking system's ex-ante economic efficiency is then strictly increasing in the project return because an increase in the project return makes the banking system's funding efficiency more important. Corollary 1 summarizes the economic efficiency of the current banking system.

Corollary 1. *The current banking system funds H-borrowers with probability π, and successfully screens L-borrowers with probability π too. The current banking system's ex-ante economic efficiency is then*

$$\mathcal{W}^c = \frac{1}{2}\left[\pi\left(R-1\right) + (1-\pi)(R_a-1)\right] + \frac{1}{2}\left[(1-\pi)(-1) + \pi(R_a-1)\right]. \tag{8}$$

We also derive borrower surplus in the equilibrium characterized in Proposition 1. On the one hand, an L-borrower will have a zero payoff ex post. On the other hand, for any H-borrower, the current banking system either does not fund her or charge all the project return. Therefore, an H-borrower cannot get any positive payoff under current banking.

Corollary 2. *Under current banking, the borrower's home bank will extract all borrower surplus, and so an H-borrower's expected payoff will be zero in equilibrium.*

Corollary 2 comes from the borrower's home bank's monopoly power, which is granted by its information advantage. Importantly, such a monopoly power exists even if there is a potential competitor: It is the severe winner's curse caused by the depositor's response that prevents bank 2 from participating in the competition.

3 Open Banking

The borrower's zero payoff derived in Corollary 2 is a key reason for central banks considering an open banking system, which aims to eliminate or weaken the home bank's information advantage to promote banking competition, so that the whole banking system can better serve the borrower. Also, it seems straightforward that when bank 2 observes an independent signal with the same quality and thus participates in the competition, the probability that the borrower gets funded significantly increases. Then, conditional on that the borrower has a high credit quality, the whole banking system will be more efficient and thus improve social welfare.

In this section, we study the proposed open banking system. We first characterize the unique symmetric equilibrium. We find that, compared with the current banking system, in such an equilibrium, while the open banking system brings the borrower a higher ex-ante payoff, it may have a low funding efficiency. More importantly, in terms of ex-ante economic efficiency, the open banking system underperforms the current banking system. The key insight we offer here is again the severe winner's curse caused by bank depositors' responses, which makes the banks refrain from funding the borrower even if they observe good signals about her credit quality.

3.1 A Symmetric Equilibrium

Since both banks observe private signals with the same quality under open banking, we first focus on a symmetric equilibrium. We first analyze a special case where $R = R_a/\pi$. In this case, the unique symmetric equilibrium is that $\beta_1^o(H) = \beta_2^o(H) = \infty$. Because the upside return of the project is low, both banks choose the risk-free investment. Note that it is impossible for both banks to bid R_a/π because the winner's curse will lead to a conditional expected payoff strictly less than $R_a - r_a$. Such a simple case suggests that even if the expected return of the borrower's project is not less than the risk-free project, it may not realize under open banking; hence, open banking may not lead to more efficient resource allocations.

We shall show that such a conclusion is true for any $R \in (R_a/\pi, 2R_a)$. We first characterize the unique equilibrium that satisfies the intuitive criterion under the open banking system when $R \in (R_a/\pi, 2R_a)$.

Proposition 2. *Suppose that $R \in (R_a/\pi, 2R_a)$. Under open banking, there is a unique symmetric equilibrium that satisfies the intuitive criterion. In equilibrium, bank i ($i = 1, 2$) does not* *make an offer to the borrower, if it receives a private signal $s_i = L$; that is, $\beta_i^o(s_i = L) = \infty$. On the other hand, if bank i observes a private signal $s_i = H$, it employs the bidding strategy*

$$\beta_i^o(H) = \begin{cases} \infty, & \text{with probability } \gamma; \\ b \in \left[\frac{R_a}{\pi}, R\right], & \text{with conditional CDF } F(b). \end{cases} \tag{9}$$

Here,

$$\gamma = \frac{(1-\pi)\pi\left(2 - \frac{R}{R_a}\right)}{\left(\frac{R}{R_a} - 1\right)\pi^2 - (1-\pi)^2}, \tag{10}$$

$$F(b) = \frac{1}{1-\gamma}\left[1 - \frac{\pi(1-\pi)\frac{2R_a - b}{R_a}}{\pi^2\frac{b-R_a}{R_a} - (1-\pi)^2}\right]. \tag{11}$$

If bank ι wins the competition, its depositor's belief is

$$\zeta(\hat{b}, \iota) = \begin{cases} \pi, & \forall \hat{b} \in \left[1, \frac{R_a}{\pi}\right); \\ \frac{\pi\left(\pi\Omega(\hat{b}) + (1-\pi)\right)}{\pi\left(\pi\Omega(\hat{b}) + (1-\pi)\right) + (1-\pi)\left((1-\pi)\Omega(\hat{b}) + \pi\right)}, & \forall \hat{b} \in \left[\frac{R_a}{\pi}, R\right], \end{cases} \tag{12}$$

where $\Omega(\hat{b}) = (1-\gamma)\left(1 - F(\hat{b})\right) + \gamma$ is the probability that bank i wins the competition by the bid $\hat{b}$ conditional on that bank j observes a signal $s_j = H$.

In the Appendix, we verify that the strategy profile and the belief system characterized by equations (9) to (12) constitute an equilibrium that satisfies intuitive criterion and show the equilibrium uniqueness. In the rest of the subsection, we discuss some interesting equilibrium properties.

First of all, both banks, when observing good signals, may not make offers to the borrower. This arises from the severe winner's curse caused by bank depositors' responses. Since the borrower does not accept any bid higher than the conditional project return R, when bank i with a signal $s_i = H$ bids R, it wins only when bank j does not bid. Then, if bank j bids for sure when receiving a good signal (i.e., $\gamma = 0$), bank i's depositor will imply from bank i's winning by a bid R that bank j surely observes a signal $s_j = L$. These two signals will then neutralize each other; as a result, bank i's depositor's posterior is $\zeta = 1/2$, and he will renegotiate an interest rate $r = 2r_a$. This largely reduces bank i's conditional expected payoff, making it refrain from making an offer. Hence, for bank i to bid R in equilibrium, bank j must choose not to bid with a sufficiently large probability.

The fact that in equilibrium, banks may not bid when receiving good signals implies that the expected payoffs of banks with good signals are just their reservation values, which are same as those when they receive bad signals. Such an equilibrium property again demonstrates that the severe winner's curse caused by bank depositors' responses plays an important role in the banking competition. We show in Section 4 that when banks' financial costs are fixed at r_a, with good signals, they always bid and get expected payoffs strictly greater than their reservation payoffs.

Two comparative statics deserve further discussions. First, γ in equation (10) is strictly decreasing in R. That is, when the conditional project return is higher, it is more likely for a bank with a good signal to make an offer to the borrower. For the intuition, consider the case that a bank bids the conditional project return R. For a fixed γ, when R increases, the bank's winning probability does not change, and so its depositor's posterior belief about the borrower's credit quality does not change either. Hence, the bank's conditional expected payoff increases. Then, to equalize its conditional expected payoff to the payoff from the risk-free investment (which must hold in equilibrium), the winner's curse to the bank has to become more severe, which requires a lower probability that the other bank does not bid when receiving a good signal (i.e., γ must decrease). Simple algebra implies that when R is very close to R_a/π, γ converges to 1, meaning that when the project return is extremely low, banks do not bid (almost surely). Also, when R approaches $2R_a$, γ approaches 0, implying that when the project return is sufficiently high, the banks with good signals offer to the borrower (almost surely).

Another interesting comparative static is how the banks' private information quality, π, affects the probability of funding the borrower. It is straightforward from equation (10) that γ is strictly decreasing in π. To understand this comparative static, we consider the case with the most severe winner's curse, that is, when bank i wins the competition by bidding R. In such a case, bank j must be choosing not to offer the borrower. Given bank j's strategy, the more precise bank i's private signal is, the more likely the borrower has a high credit quality, and the less severe the winner's curse is. Therefore, in equilibrium, banks will offer the borrower with higher probability (or, equivalent, lower γ).

Another important feature of our model is that banks, when competing with each other, also send signals to their depositors about their private signals. Therefore, the depositors' off-equilibrium path beliefs may lead to multiple equilibria. Indeed, there is an equilibrium in which banks with good signals bid over $[R_a/\pi, \tilde{b}]$, where $\tilde{b} < R$. Such equilibria need the support of the depositors' off-equilibrium path belief that for any $b' \in (\tilde{b}, R]$, the winning bank ι receives a bad signal with sufficiently high probability; otherwise, banks can profitably deviate to b' without causing higher financial cost. This off-equilibrium path belief, however, fails the intuitive criterion test: A bank with a bad signal never bids even if it is perceived to receive a good signal, so only a bank who receives a good signal may deviate to b'. Hence, the model has a unique equilibrium that satisfies the intuitive criterion.

3.2 Economic Efficiency of Open Banking System

In this subsection, we compare the open banking system with the current banking system in funding efficiency, screening efficiency, ex-ante efficiency, and borrower surplus. We assume that under the open banking system, all agents are playing the symmetric equilibrium characterized in Proposition 2.

We first analyze the open banking's funding efficiency that is measured by the probability that the open banking system funds high credit quality borrowers. Denote by $\mathcal{P}_H^o(R)$ the probability that the open banking system funds an H-borrower with a project return $R \in (R_a/\pi, 2R_a)$. Obviously, the higher the probability $\mathcal{P}_H^o(R)$, the higher the open banking system's funding efficiency, and if $\mathcal{P}_H^o(R) \geq \pi$, the open banking system serves H-borrowers better than the current banking system.

Since a bank never makes an offer to the borrower when observing a bad signal, and it does not make a bid with probability γ even if it observes a good signal, we calculate that

$$\mathcal{P}_H^o(R) = \pi^2(1-\gamma^2) + 2\pi(1-\pi)(1-\gamma). \tag{13}$$

In equation (13), the first term is the probability that both banks receive good signals and at least one bank funds the borrower, and the second term is the probability that exactly one bank receives a good signal and it funds the borrower.

We find that the open banking system may not be able to serve high-quality borrowers better than the current banking system when the conditional project return R is low. This is formally stated in Proposition 3 and illustrated in Figure 1.

Proposition 3. *Suppose that under the open banking system, the agents play a symmetric equilibrium. There is a $R_H \in (R_a/\pi, 2R_a)$ such that the open banking system serves an H-borrower better than the current banking system, if and only if $R \geq R_H$.*

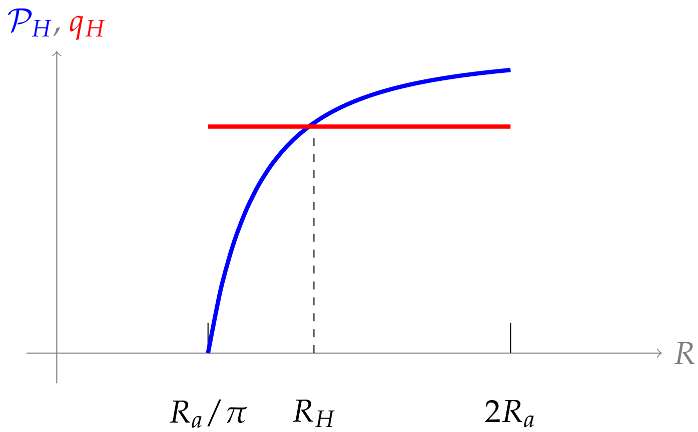

Figure 1: Comparison between open banking and current banking in terms of funding efficiency. $\mathcal{P}_H$ is the probability of the H-borrower getting funded under open banking and q_H is that under current banking.

Proposition 3 arises from the exacerbated winner's curse due to depositors' responses to bank investments. As we analyzed, as R increases, a bank with a good signal is more likely to make an offer to the borrower because the increase in the conditional project return alleviates the most severe winner's curse (which occurs when a bank wins by bidding R). Then, as R increases, the open banking system is more likely to fund an H-borrower. In addition, as R approaches $2R_a$, γ converges to 0; that is, when a bank observes a good signal, it will surely make an offer to the borrower. So, when the conditional project return is high, an H-borrower is likely to get funded by the open banking system with the two banks receiving independent informative signals. On the other extreme, when R approaches R_a/π, the winner's curse caused by bank depositors' responses dominates bank expected payoff, so that neither bank makes an offer with a significant probability. Therefore, an H-borrower is very unlikely to be funded by the open banking system, even if it is more likely to generate at least one good signal (than the current banking system).

Another important role banks play is to screen low credit quality borrowers. We denote by $\mathcal{P}_L^o$ the probability that an L-borrower is funded in the symmetric equilibrium. Then, the smaller the probability $\mathcal{P}_L^o$ is, the higher the open banking system's screen efficiency is, and the open banking system better screens L-borrowers than the current banking system if $\mathcal{P}_L^o \leq 1 - \pi$. We then derive $\mathcal{P}_L^o$ as

$$\mathcal{P}_L^o = (1-\pi)^2(1-\gamma^2) + 2\pi(1-\pi)(1-\gamma). \tag{14}$$

Proposition 4 shows that the open banking system can better screen L-borrowers than the current banking system only when the project return is low. This is illustrated in Figure 2.

Proposition 4. *Suppose that under the open banking system, the agents play a symmetric equilibrium. Then, there is $R_L \in (R_a/\pi, 2R_a)$ such that the open banking system better screens low credit quality borrowers than the current banking system if and only if $R \leq R_L$.*

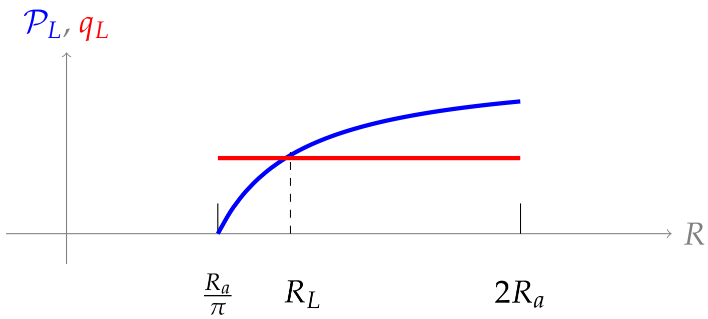

Figure 2: Comparison between open banking and current banking in terms of screening efficiency. $\mathcal{P}_L$ is the probability of the L-borrower getting funded under open banking and q_L is that under current banking.

The intuition of Proposition 4 is similar to that of Proposition 3. When the project return is small, under the open banking system, the banks do not offer to fund the borrower, and so they are less likely to fund L-borrowers than the banks under the current banking system. On the other hand, when the project return is high, it is more likely that at least one bank offers the borrower under the open banking system than under the current banking system. Therefore, for large project returns, the open banking system underperforms the current banking system in terms of the screening efficiency.

We finally study the ex-ante economic efficiency of the open banking, which is measured by

$$\begin{aligned}\mathcal{W}^o(R) =& \frac{1}{2}\left[\mathcal{P}_H^o\,(R-1) + (1-\mathcal{P}_H^o)\,(R_a-1)\right] \\ &+ \frac{1}{2}\left[\mathcal{P}_L^o\,(-1) + (1-\mathcal{P}_L^o)\,(R_a-1)\right]. \end{aligned} \tag{15}$$

Proposition 5 then shows that in terms of the ex-ante economic efficiency, the open banking system underperforms the current banking system.

Proposition 5. *Suppose that the agents play the symmetric equilibrium characterized in Proposition 2. For any $R \in (R_a/\pi, 2R_a)$, the open banking system leads to lower ex-ante economic efficiency than the current banking system.*

Intuitively, a banking system's ex-ante economic efficiency is the average of its funding efficiency and its screening efficiency, after taking into account the conditional economic gain and loss. As the conditional project return R increases from R_a/π to $2R_a$, a banking system's funding efficiency becomes more important, since once an H-borrower is funded, the economic efficiency will increase. On the other hand, the importance of a banking system's screening efficiency remains the same as R increases because successfully screening an L-borrower always leads to a return from the risk-free investment R_a. Hence, relative to the screening efficiency, as R increases, a banking system's funding efficiency plays a more important role in determining its ex-ante economic efficiency.

Compared with the current banking system, the open banking system is better at screening L-borrowers when R is low and is better at funding H-borrowers when R is high. Therefore, the difference between the open banking's economic efficiency and the current banking system's economic efficiency is non-monotonic in R. Indeed, simple algebra shows that R_L, the threshold above which the current banking system screens L-borrowers better, is strictly less than R_H, the threshold above which the open banking system serves H-borrowers better. Hence, it follows from Proposition 3 and Proposition 4 that for any $R \in (R_L, R_H)$, the open banking system underperforms the current banking system in both funding high credit quality borrowers and screening low credit quality borrowers.

Therefore, the open banking system may outperforms the current banking system only when R is close to R_a/π or when R is close to $2R_a$. However, in the former case, the open banking system is too conservative due to the winner's curse and gives up the potential project return completely (whose expected return is R_a/π absent the winner's curse), so the economic efficiency of the open banking system equals that of the current banking system. In the other extreme, where R increases to $2R_a$, the ex-ante economic efficiency of the open banking system increases to that of the current banking system because the expected return of the borrower's project is just the same as the risk-free project return. Hence, for any $R \in (R_a/\pi, 2R_a)$, the open banking system underperforms the current banking system.

The comparison between open banking and current banking in terms of economic efficiency is illustrated in Figure 3. Obviously, the difference economic efficiency under open banking and under current banking, $\mathcal{W}^o(R) - \mathcal{W}^c(R)$, first decreases and then increases in the conditional project return R.

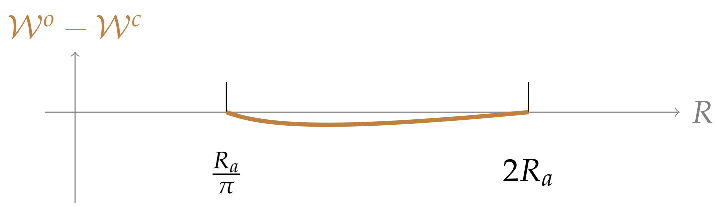

Figure 3: Comparison between open banking and current banking in terms of economic efficiency.

While Proposition 5 shows that the open banking system underperforms the current banking system in terms of ex-ante economic efficiency, it does improve an H-borrower's expected payoff.

Corollary 3. *Suppose that the agents play the symmetric equilibrium characterized in Proposition 2. An H-borrower's equilibrium expected payoff is strictly positive.*

Corollary 3 arises directly from the banks' competition. Under current banking, the borrower's home bank is a monopoly and so takes all the project return away from the borrower. Under open banking, however, a bank with a good signal bids an amount lower than the project return to increase the winning probability and the conditional expected payoff. Therefore, some surplus is left to the borrower, leading to a strictly positive borrower's payoff.

3.3 Asymmetric Equilibria

In subsection 3.2, we study the open banking system's economic efficiency under the assumption that agents are playing the unique symmetric equilibrium that satisfies the intuitive criterion. In this section, we extend our analysis by allowing banks to employ asymmetric bidding strategies and study whether the open banking system can perform better in an asymmetric equilibrium.

We find that the model has a continuum of asymmetric equilibria, which are characterized in Proposition 6 below.

Proposition 6. *Under open banking, for any $R \in (R_a/\pi, 2R_a)$, there is an asymmetric equilibrium. In equilibrium, $\beta_1^{oa}(L) = b_2^{oa}(L) = \infty$,*

$$\beta_i^{oa}(H) = \begin{cases} \infty, & \text{with probability } \gamma; \\ b \in \left[\frac{R_a}{\pi}, R\right), & \text{with conditional CDF } F(b), \end{cases} \tag{16}$$

and

$$\beta_j^{oa}(H) = \begin{cases} \infty, & \text{with probability } \chi \geq 0; \\ R, & \text{with probability } \rho > 0; \\ b \in \left[\frac{R_a}{\pi}, R\right), & \text{with conditional CDF } F(b). \end{cases} \tag{17}$$

If bank i wins the competition, its depositor's belief is

$$\zeta(\hat{b}, i) = \begin{cases} \pi, & \forall \hat{b} \in \left[1, \frac{R_a}{\pi}\right); \\ \frac{\pi\left(\pi\Omega(\hat{b})+(1-\pi)\right)}{\pi\left(\pi\Omega(\hat{b})+(1-\pi)\right)+(1-\pi)\left((1-\pi)\Omega(\hat{b})+\pi\right)}, & \forall \hat{b} \in \left[\frac{R_a}{\pi}, R\right), \end{cases} \tag{18}$$

and if bank j wins the competition, its depositor's belief is

$$\zeta(\hat{b}, j) = \begin{cases} \pi, & \forall \hat{b} \in \left[1, \frac{R_a}{\pi}\right); \\ \frac{\pi\left(\pi\Omega(\hat{b})+(1-\pi)\right)}{\pi\left(\pi\Omega(\hat{b})+(1-\pi)\right)+(1-\pi)\left((1-\pi)\Omega(\hat{b})+\pi\right)}, & \forall \hat{b} \in \left[\frac{R_a}{\pi}, R\right); \\ \frac{\pi(\pi\gamma+(1-\pi))}{\pi(\pi\gamma+(1-\pi))+(1-\pi)((1-\pi)\gamma+\pi)}, & \text{if } \hat{b} = L. \end{cases} \tag{19}$$

Here, γ, $F(b)$, $\Omega(\hat{b})$ are defined as in Proposition 2, and $\chi + \rho = \gamma$. The equilibrium is unique up to $\chi \in [0, \gamma)$.

The idea of constructing an asymmetric equilibrium is as follows. First of all, the only possibility to construct an asymmetric equilibrium is to allow one bank to bid an amount $b < \infty$ with positive mass; otherwise, banks' indifference conditions imply a symmetric equilibrium. We show that such an amount cannot be in $(R_a/\pi, R)$ due to the competition; it cannot be at R_a/π, since otherwise, the other bank, when bidding arbitrarily close to R_a/π, will get an expected payoff strictly less than the reservation value. Hence, the mass point can only be R. From the symmetric equilibrium characterized in Proposition 2, one bank will move some mass from not bidding to the amount R, and it is easy to show that this is an equilibrium, and both banks' expected payoffs are just their reservation value.

We now analyze the effect of the open banking system on economic efficiency, assuming that the agents are playing an asymmetric equilibrium characterized in Proposition

6. Lemma 2 shows that the ex-ante economic efficiency of the open banking system is independent of how bank j divides the mass γ between $b_j = R$ and $b_j = \infty$.

Lemma 2. *Suppose that the agents are playing an asymmetric equilibrium characterized in Proposition 6 with a $\chi \in [0, \gamma)$. For any $\chi \in [0, \gamma)$, $\mathcal{W}^o(\chi) = \mathcal{W}^o(\gamma)$.*

Lemma 2 arises from the fact that the marginal funding effect of the bidding probability of bank j (i.e., an increase in ρ) is just offset by its marginal screening effect. Then, Lemma 2 and Proposition 5 directly imply that ex ante, the open banking system underperforms the current banking system in terms of economic efficiency, even if banks are allowed to employ asymmetric strategies.

Proposition 7. *For any $R \in (R_a/\pi, 2R_a)$, the open banking system underperforms the current banking system in terms of ex-ante economic efficiency. This result is robust across all equilibria under open banking.*

We also find that the equilibrium selection under open banking does not matter for the borrower's surplus. Suppose that bank i does not lend to the borrower, and bank j observes a signal $s_j = H$. Then, if $b_j = \infty$, the borrower is not funded and gets a payoff zero, while if $b_j = R$, the borrower's payoff is also zero even if it is funded by bank j because bank j will get all the project return. Therefore, allowing banks to play asymmetric strategy will not affect the borrower's expected payoff.

Corollary 4. *Under the open banking system, the borrower's expected payoff is constant across all equilibria and is strictly greater than that under the current banking system.*

4 Depositor Monitoring

We highlight the role of bank depositors' responses in banking competition in Section 2 and Section 3. In particular, it is their responses that aggravate the winner's curse in the banking competition, which leads to the borrower's home bank's monopoly power under current banking and banks' refrainment from making offers to the borrower under open banking.

The assumption that bank depositors renegotiate with the banks arises from the maturity mismatch in the bank industry in practice and is supported by recent empirical evidence (Chen et al., 2021a,b). Since banks' deposits usually have shorter maturity than their investments, banks need to roll over their deposits. During such a rollover, the banks and their depositors will renegotiate the interest rates.

In this section, we further demonstrate the role of bank depositors' responses in determining banking systems' economic efficiency. To reach this goal, we assume that any bank deposit's maturity matches its investment. Therefore, at the end of the game, each bank will pay its depositor r_a if it does not default. To simplify the algebra, we assume that the lower bound of R is $R_a/\pi = 2R_a - r_a$, and hence $r_a/R_a = (2\pi - 1)/\pi$.[9]

We find that there is a unique equilibrium under the current banking system. In such an equilibrium, bank 1 (the borrower's home bank) always makes a bid to the borrower when it receives a good signal but will not make a bid to the borrower when it receives a bad signal. On the other hand, differing from the case where the depositor responds to the bank's investment decision, bank 2 bids with a positive probability in equilibrium.

Proposition 8. *Suppose that the banks' financial costs are fixed at r_a. Under current banking, for any $R \in (R_a/\pi, 2R_a)$ (or any $z = R/R_a \in (1/\pi, 2)$), there is a unique equilibrium. In such an equilibrium, bank 1 always makes an offer to the borrower when observing a good signal but does not do so when observing a bad signal. Bank 2 will make an offer to the borrower too with a probability $1 - \chi$, where*

$$\chi = \frac{(1-\pi)(2\pi-1)}{\pi(\pi z - 1) + (1-\pi)(2\pi - 1)}. \tag{20}$$

The difference between Proposition 8 and Proposition 1 is that when bank 2's depositor does not respond to its investment, its financial cost will stay at a low level. This alleviates the winner's curse, so that when bank 1 may bid very high (a mass at R), bank 2's winning will not lead to a conditional payoff strictly less than risk-free investment payoff. Hence, bank 2 may bid in equilibrium without its depositor's "monitoring."

Under the current banking system, the ex-ante economic efficiency is

$$\mathcal{W}^c(r_a) = \frac{1}{2}\left[q_H(R-1) + (1-q_H)(R_a - 1)\right] + \frac{1}{2}\left[q_L(-1) + (1-q_L)(R_a-1)\right], \tag{21}$$

where

$$q_H = 1 - (1-\pi)\chi, \tag{22}$$
$$q_L = 1 - \pi\chi. \tag{23}$$

[9]Simple algebra shows that this is consistent with equation (5).

Because $R \leq 2R_a$, it is optimal not to fund the borrower ex ante. Then, since bank 2 who does not have any new information about the borrower's credit quality participate, the current banking system's economic efficiency is lower (compared with Corollary 1).

We now consider the open banking system. We find that in equilibrium, both banks will make offers to the borrower if they observe good signals.

Proposition 9. *Suppose that the banks' financial costs are fixed at r_a. Under the open banking system, for any $R \in (R_a/\pi, 2R_a]$, there is a unique equilibrium. In such an equilibrium, bank i will bid if and only if it observes a good signal.*

Therefore, when $\theta = H$, the open banking system has conditional economic efficiency $\mathcal{P}_H(R-1) + (1-\mathcal{P}_H)(R_a-1)$, and when $\theta = L$, the open banking system has conditional economic efficiency $\mathcal{P}_L(R-1) + (1-\mathcal{P}_L)(R_a-1)$. The ex-ante economic efficiency is then

$$\mathcal{W}^o(r_a) = \frac{1}{2}\left[\mathcal{P}_H(R-1) + (1-\mathcal{P}_H)(R_a-1)\right] + \frac{1}{2}\left[\mathcal{P}_L(-1) + (1-\mathcal{P}_L)(R_a-1)\right], \quad (24)$$

where

$$\begin{aligned} \mathcal{P}_H &= 1-(1-\pi)^2, & (25)\\ \mathcal{P}_L &= 1-\pi^2. & (26) \end{aligned}$$

The main difference between Proposition 9 and Proposition 2 is that without "depositor monitoring," banks behave more aggressively: Both banks offer the borrower for sure when they observe good signals. Such behavior makes both $\mathcal{P}_H$ and $\mathcal{P}_L$ larger than when the depositors do respond to bank investments. Again, $R \leq 2R_a$ suggests that the banks' screening role is more important, so the economic efficiency of the open banking system should be lower than the case where the depositors respond to bank investments.

Then, without the depositors' monitoring, does the open banking system still underperform the current banking system in terms of economic efficiency? We have

$$\mathcal{W}^o(r_a) - \mathcal{W}^c(r_a) = \frac{R_a}{2}\left[\left(\mathcal{P}_H - q_H\right)(z-1) + \left(q_L - \mathcal{P}_L\right)\right]. \quad (27)$$

We calculate that at $z = 1/\pi$, $\mathcal{W}^o(r_a) - \mathcal{W}^c(r_a) < 0$, implying that when the project return is small, the open banking system has lower economic efficiency. However, at $z = 2$, $\mathcal{W}^o(r_a) - \mathcal{W}^c(r_a) > 0$, meaning that the open banking system, without bank depositors' monitoring, will lead to higher economic efficiency when the project return is high. The latter arises from bank 2's very aggressive behavior under the current banking system (it offers the borrower with probability π even if the borrower's ex-ante credit quality is low, and it does not have any new information about the borrower's credit quality).

Further algebra shows that $\mathcal{W}^o(r_a) - \mathcal{W}^c(r_a)$ is strictly increasing, which implies Proposition 10 below. It is also illustrated in Figure 4.

Proposition 10. *Suppose that the banks' financial costs are fixed at r_a. There is a $\tilde{R} \in (R_a/\pi, 2R_a)$ such that when $R \in \left(\tilde{R}, 2R_a\right]$, $\mathcal{W}^o(r_a) > \mathcal{W}^c(r_a)$.*

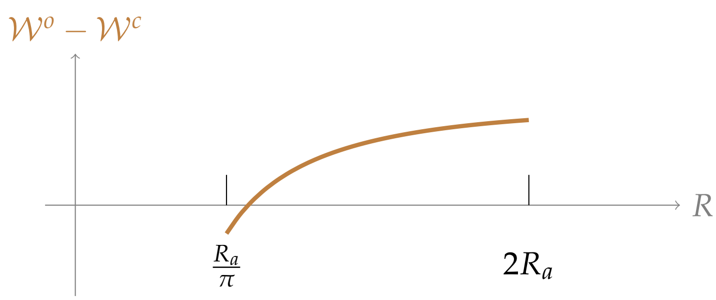

Figure 4: Comparison between open banking and current banking in terms of economic efficiency without depositor monitoring.

Obviously, Proposition 10 differs from Proposition 5. Such a difference not only demonstrates the role of bank depositors' responses in determining banking system's economic efficiency, but also suggests that the open banking system can lead to higher economic efficiency when the maturity mismatch, one most important feature of the banking industry, can be resolved.

5 Conclusion

Open banking allows borrowers to freely share their data with any financial institutions. While its benefits have been widely accepted, the open banking's impact on the financial system's health and stability is less known. This has become one major reason why central banks of many developed countries are hesitating to adopt open banking.

This paper proposes a banking competition model to discuss this question. In our model, bank depositors will renegotiate with banks when they lend to the borrower. It turns out that depositors' monitoring, which is an inherent feature under any banking system, plays a critical role in determining banking competition, borrower welfare, and resource allocation. In particular, bank depositors' monitoring exacerbates the winner's curse, which makes borrowers' home banks informational monopolists under current banking and leads banks with good signals refrain from serving the borrowers under open banking.

We show that because of banking competition, borrower welfare surely increases. However, open banking may lead to inefficient resource allocation. As the borrower's conditional project return increases, the effect of depositor monitoring becomes weaker. Therefore, open banking outperforms current banking in funding efficiency only when the conditional project return is high and in screening efficiency only when the conditional project return is low. However, open banking underperforms current banking in terms of ex-ante economic efficiency.

In addition to the contributions to the discussion of open banking, our paper contributes to lending market competition. Financial intermediaries, when making investment decisions, have to consider the effects of their investments on future financial costs. We show that once such a feedback is taken into account, financial intermediaries' behavior may be very different from what is predicted in the literature.

Our paper has also theoretical contributions. In our model, the winning bidder's action also signals her private signal about the object, which will affect her expected payoff. This feature has been largely overlooked in the literature on common-value auctions.

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A Omitted Proofs

In this section, we present all omitted proofs.

Proof of Lemma 1:

Given any bank 1's bidding strategy, which is monotonic, if bank 2 quotes $\hat{b}$ in equilibrium and wins the competition, its depositor's belief will be maximized when it can win the competition for sure. Also, since bank 2 does not have any information beyond the prior, when $\hat{b}$ wins for sure, bank 2's depositor does not update his belief about the borrower's credit quality. Hence,

$$\zeta(\hat{b}, \iota = 2) \leq \frac{1}{2}.$$

Therefore, bank 2's financial cost will be

$$r = \frac{r_a}{\zeta(\hat{b}, \iota = 2)} \geq 2r_a.$$

Then, bank 2's conditional (on winning) payoff is

$$\begin{aligned} U_2 &= \Pr(\text{Bank 2 wins with } \hat{b})(\hat{b} - r) \\ &\leq \frac{1}{2}(R - r) \\ &< \frac{1}{2}(2R_a - 2r_a) \\ &= R_a - r_a, \end{aligned}$$

for any $R \in (R_a/\pi, 2R_a)$. So, it is profitable for Bank 2 to deviate to the risk-free investment. This implies that Bank 2 will not bid in equilibrium under the current banking system.

Q.E.D.

Proof of Proposition 1:

We first verify that bank 1's strategy profile in equation (6) and its depositor's belief in equation (7) constitute an equilibrium. Obviously, if bank 1 observes a signal $s_1 = H$, bidding $b_1 \in (1, R]$ guarantees a winning. So, any bids $b_1 < R$ will be dominated by $b_1 = R$. Now, with $b_1 = R$, bank 1's expected payoff is

$$U_1(R, H) = \pi(R - r) > \pi\left(\frac{R_a}{\pi} - \frac{r_a}{\pi}\right) = R_a - r_a;$$

that is, the bid $b_1 = R$ brings bank 1 a higher expected payoff than the risk-free investment. Therefore, bank 1 will not deviate away from $b_1 = R$, when it receives a signal $s_1 = H$.

If bank 1 receives a signal $s_1 = L$, bidding $b_1 \in (1, R]$ will also win the competition. Then, its expected payoff

$$U_1(b_1, L) \leq (1-\pi)\left(R - \frac{r_a}{\pi}\right) < (1-\pi)\left(2R_a - \frac{r_a}{\pi}\right).$$

It then follows from equation (5) that

$$(1-\pi)\left(2R_a - \frac{r_a}{\pi}\right) < R_a - r_a.$$

Therefore, $U_1(b_1, L) < R_a - r_a$, implying that bank 1, when receiving a signal $s_1 = L$, will not bid.

Finally, there are indeed other equilibria. The fact that $U_1(b_1, L) < R_a - r_a$ for any $b_1 \in (1, R]$ even if $\zeta(b_1, \iota = 1) = \pi$ implies that bank 1 with $s_1 = L$ does not bid in equilibrium. However, for any $\hat{b} \in \left(\frac{R_a}{\pi}, R\right)$ there is an equilibrium in which bank 1 bids $\hat{b}$ when it receives the signal $s_1 = H$. Such an equilibrium is supported by the off-equilibrium path belief $\zeta(b', \iota = 1) < \pi$ for all $b' \in \left(\hat{b}, R\right]$. However, such an off-equilibrium path belief violates the intuitive criterion. Specifically, for any belief following $b' \in \left(\hat{b}, R\right]$, bank 1 with $s_1 = L$ does not bid, even if it is perceived to receive a signal $s_1 = H$. So if the winning bid is b', bank 1's depositor should believe that bank 1 receives the signal $s_1 = H$. Hence, under the current banking system, there is a unique equilibrium passing the intuitive criterion test, which is the one characterized in the proposition.

Q.E.D.

Proof of Proposition 2:

First of all, observing a private signal $s_i = L$, bank i does not bid; otherwise, if it wins, its conditional expected payoff is less than

$$\frac{1}{2}\left[R - \frac{r_a}{\pi}\right],$$

which is less than $R_a - r_a$. Therefore, bank i will bid when $s_i = L$.

Second, it is straight forward to verify that equation (11) defines a valid cumulative distribution function. Then, given bank j's bidding strategy, if bank i bids an amount $\hat{b} \in$

$[R_a/\pi, R]$ and wins the competition, bank i will update its belief about the borrower's credit quality as

$$\frac{\pi\left(\pi\Omega(\hat{b})+(1-\pi)\right)}{\pi\left(\pi\Omega(\hat{b})+(1-\pi)\right)+(1-\pi)\left((1-\pi)\Omega(\hat{b})+\pi\right)}, \quad \forall \hat{b}\in\left[\frac{R_a}{\pi}, R\right],$$

which is just $\zeta(\hat{b}, \iota = 1)$ defined in equation (12). Therefore, conditional on winning the competition by a bid $\hat{b} \in [R_a/\pi, R]$, bank i believes that bank j observes a signal $s_j = H$ with probability

$$\Omega(\hat{b}) = \frac{\pi(1-\pi)\left(\frac{2R_a-b}{R_a}\right)}{\pi^2\frac{b-R_a}{R_a}-(1-\pi)^2}.$$

Therefore, bank i's conditional expected payoff is

$$U_i(\hat{b}, H) = \zeta(\hat{b}, \iota = i)\hat{b} - r_a = R_a - r_a = U_i(\infty, H).$$

Hence, given bank j's bidding strategy, bank i does not have profitable deviations from the strategy prescribed.

Also, $\zeta(\hat{b}, \iota)$ is consistent. Since $\beta_i^o(L) = \infty$, any $\hat{b} \in (1, R]$ will lead to a belief that bank ι observes a private signal $s_\iota = H$. Then, given the other bank's strategy, the fact that bank ι wins implies that the other bank observes a good private signal with probability $\Omega(\hat{b})$. Then, $\zeta(\hat{b}, \iota)$ follows Bayes rule.

The equilibrium uniqueness follows the arguments of necessary conditions for an equilibrium. First of all, it is straightforward to show that in equilibrium, the banks will not bid an amount $\tilde{b} \in (R_a/\pi, R]$ with strictly positive probability. Otherwise, any bank can profitably deviate from $\tilde{b}$ to $\tilde{b} - \epsilon$ (where $\epsilon > 0$ is sufficiently close to zero) because such a deviation will discretely reduce the winner's curse and so discretely increase the conditional (on winning) expected payoff. This is similar to the argument in the classic common-value auctions. Further calculation also shows that the banks will not bid R_a/π with a probability $\rho > 0$ in equilibrium. Otherwise, their conditional (on winning) expected payoff will be

$$\begin{aligned}
& V_i\left(\frac{R_a}{\pi}, H\right) \\
= \;& \frac{\pi\left[\pi\left(1-\frac{\rho}{2}\right)+(1-\pi)\right]}{\pi\left[\pi\left(1-\frac{\rho}{2}\right)+(1-\pi)\right]+(1-\pi)\left[(1-\pi)\left(1-\frac{\rho}{2}\right)+\pi\right]}\left(\frac{R_a}{\pi}\right)-r_a \\
< \;& R_a - r_a.
\end{aligned} \tag{28}$$

Second, both banks get an expected payoff $R_a - r_a$ in equilibrium. Since both banks will use a mixed strategy without any mass, when bank i bids the maximum amount $\bar{b}$ (or the bid converges to the upper bound of the support of the bidding strategy), it wins only when bank j observes the private signal $s_j = L$. Therefore, if the banks always bid an amount in $[R_a/\pi, R]$ when receiving a good signal, the winning bank and its depositor will believe that the borrower has a high credit quality with probability 1/2. Hence, by bidding $\bar{b}$, bank i's conditional payoff is

$$V_i(\bar{b}, H) = \frac{1}{2}\left(\bar{b} - 2r_a\right) \leq \frac{1}{2}R - r_a < R_a - r_a. \tag{29}$$

As a result, in a symmetric equilibrium, with a positive probability $\gamma > 0$, each bank chooses not to bid even if it receives a good signal. This implies that each bank's equilibrium conditional payoff is $R_a - r_a$.

Third, the upper bound of the support of a bank's equilibrium bidding strategy is $\bar{b} = R$. If not, a bank may consider a deviation from a bid $b' \leq \bar{b}$ that is sufficiently close to $\bar{b}$ to a bid R. Such a deviation does not change the winner's curse but significantly increases the bank's payoff when the borrower does not default. Note that there may be symmetric equilibria in which $\bar{b} < R$. Such equilibria need the support of the off-equilibrium path belief that a bank that makes a bid $b' \in \left(\bar{b}, R\right)$ receives a bad signal. Such a belief system, however, violates the intuitive criterion. As we argued, if a bank receives a bad signal, it will not make a bid even if it is perceived to receive a good signal. Hence, the deviation b' can only be made by a bank with a good signal, which means that a plausible belief following a deviation $b' \in \left(\bar{b}, R\right)$ must be that the bank that bids b' receives a good signal.

Fourth, the lower bound of the support of a bank's equilibrium bidding strategy is $\underline{b} = R_a/\pi$. Since there is no mass point in banks' strategy, when a bank bids $\underline{b}$, it will surely wins the competition. In this case, winning the competition is not informative at all, and so the winning bank and its depositor will have the belief $\zeta(\underline{b}, \iota) = \pi$. Since a bank's equilibrium conditional expected payoff is $R_a - r_a$, we can calculate that

$$V_i(\underline{b}, H) = \pi\left(\underline{b} - \frac{r_a}{\pi}\right) = R_a - r_a. \tag{30}$$

As a result, $\underline{b} = R_a/\pi$.

Finally, it is straightforward that there is no "hole" in a bank's equilibrium bidding strategy; otherwise, the bank will deviate from the lower bound of the hole to the upper bound of the hole.

Therefore, in a symmetric equilibrium, neither bank bids when receiving a bad signal; when receiving a good signal, a bank will bid over the support $[R_a/\pi, 2R_a] \cup \{\infty\}$ with no mass point in $[R_a/\pi, 2R_a]$ and a strictly positive probability γ at ∞. Then, γ and $F(b)$ are uniquely pinned down by $U_i(b, H) = R_a - r_a$. This completes the proof of the proposition.

Q.E.D.

Proof of Proposition 3:

According to equation (13), the probability that the open banking system serves an H-borrower with a project return $R \in [R_a/\pi, 2R_a]$ is

$$\mathcal{P}_H^o(R) = \pi^2(1-\gamma^2) + 2\pi(1-\pi)(1-\gamma).$$

It then follows from equation (10) that γ is strictly decreasing in R, and so $\mathcal{P}_H^o(R)$ is strictly increasing in R. In addition, as $R \to R_a/\pi$, $\gamma \to 1$, and $\mathcal{P}_H^o \to 0$; as $R \to 2R_a$, $\gamma \to 0$, and $\mathcal{P}_H^o \to \pi(2-\pi) > \pi$. Therefore, there is a $R_H \in (R_a/\pi, 2R_a)$ such that $\mathcal{P}_H^o > \mathcal{P}_H^c$ if and only if $R \geq R_H$.

To characterize R_H, we set

$$\mathcal{P}_H^o(R) = \pi.$$

That is, conditional on $\theta = H$, the probability that the open banking system serves the borrower equals the probability that the current banking system serves the borrower. Since γ is strictly decreasing in R, we characterize γ_H, which equalizes $\mathcal{P}_H^o = \pi$. We get

$$\gamma_H = \frac{\sqrt{1-\pi} - (1-\pi)}{\pi} = \frac{\sqrt{1-\pi}}{1+\sqrt{1-\pi}}, \tag{31}$$

which in turn determines R_H by equation (10).

Q.E.D.

Proof of Proposition 4:

By equation (14), the probability that the open banking system serves an L-borrower with a project return $R \in [R_a/\pi, 2R_a]$ is

$$\mathcal{P}_L^o = (1-\pi)^2(1-\gamma^2) + 2\pi(1-\pi)(1-\gamma).$$

Recall from Corollary 1 that under the current banking system, an L-borrower is funded with probability $1-\pi$. Therefore, the open banking system screens low credit quality borrowers better than the current banking system if and only if $\mathcal{P}_L^o \leq 1-\pi$. Since γ is strictly decreasing in R, $\mathcal{P}_L^o$ is strictly increasing in R. Note that $\mathcal{P}_L^o \to 0$ as $R \to R_a/\pi$ and that $\mathcal{P}_L^o \to 1-\pi^2 > 1-\pi$ as $R \to 2R_a$. Therefore, there is $R_L \in (R_a/\pi, 2R_a)$ such that the open banking system screens low credit quality borrowers better if and only if $R \leq R_L$.

Again, we characterize R_L by characterizing γ_L that equalizes $\mathcal{P}_L^o = 1-\pi$. We get

$$\gamma_L = \frac{\sqrt{\pi}-\pi}{1-\pi} = \frac{\sqrt{\pi}}{1+\sqrt{\pi}}, \tag{32}$$

which in turn determines R_L by equation (10).

Q.E.D.

Proof of Proposition 5:

It follows from equations (8) and (15) that the difference between the ex-ante economic efficiency of the open banking system and that of the current banking system is

$$\mathcal{W}^o - \mathcal{W}^c = \frac{R_a}{2}\left[(\mathcal{P}_H^o - \pi)\, z + (1 - \mathcal{P}_H^o - \mathcal{P}_L^o)\right], \tag{33}$$

where $z = R/R_a \in [1/\pi, 2]$.

As $z \to 1/\pi$, since both $\mathcal{P}_H^o$ and $\mathcal{P}_L^o$ converge to 0, $\mathcal{W}^o - \mathcal{W}^c = 0$. On the other hand, as $z \to 2$, because $\mathcal{P}_H^o \to \pi(2-\pi)$ and $\mathcal{P}_L^o \to 1-\pi^2$, $\mathcal{W}^o - \mathcal{W}^c = 0$ too.

Therefore, whether the open banking system will lead to higher or lower ex-ante economic efficiency depends on the value of $\mathcal{W}^o - \mathcal{W}^c$ when $z \in (1/\pi, 2)$. We differentiate $\mathcal{W}^o - \mathcal{W}^c$ with respect to z and get

$$\begin{aligned}\frac{\mathrm{d}}{\mathrm{d}z}\left(\mathcal{W}^o - \mathcal{W}^c\right) = \frac{R_a}{2}\Bigg[&\left(\pi^2(1-\gamma^2) + 2\pi(1-\pi)(1-\gamma) - \pi\right)\\ &+ \frac{\mathrm{d}\gamma}{\mathrm{d}z}\left(\frac{\mathrm{d}\mathcal{P}_H^o}{\mathrm{d}\gamma} z - \frac{\mathrm{d}\mathcal{P}_H^o}{\mathrm{d}\gamma} - \frac{\mathrm{d}\mathcal{P}_L^o}{\mathrm{d}\gamma}\right)\Bigg].\end{aligned} \tag{34}$$

Substituting $\mathcal{P}_H^o$, $\mathcal{P}_L^o$, and γ into equation (34), we get

$$\frac{\mathrm{d}\mathcal{P}_H^o}{\mathrm{d}\gamma} z - \frac{\mathrm{d}\mathcal{P}_H^o}{\mathrm{d}\gamma} - \frac{\mathrm{d}\mathcal{P}_L^o}{\mathrm{d}\gamma} = 0,$$

and so

$$\frac{\mathrm{d}}{\mathrm{d}z}\left(\mathcal{W}^o - \mathcal{W}^c\right) = \frac{R_a}{2}\left(\pi^2(1-\gamma^2) + 2\pi(1-\pi)(1-\gamma) - \pi\right).$$

Then, as $z \to (1/\pi)^+$, $\gamma \to 1$, $\mathrm{d}(\mathcal{W}^o - \mathcal{W}^c)/\mathrm{d}z < 0$; as $z \to 2^-$, $\gamma \to 0$, $\mathrm{d}(\mathcal{W}^o - \mathcal{W}^c)/\mathrm{d}z > 0$. Therefore, if and only if there is a unique $\hat{\gamma} \in (0,1)$ such that $\mathrm{d}(\mathcal{W}^o - \mathcal{W}^c)/\mathrm{d}z = 0$, $\mathcal{W}^o - \mathcal{W}^c < 0$ for all $z \in (1/\pi, 2)$. This is true by solving the quadratic equation

$$\pi^2(1-\gamma^2) + 2\pi(1-\pi)(1-\gamma) - \pi = 0.$$

It turns out that this equation has a unique solution between 0 and 1, that is,

$$\hat{\gamma} = \frac{\sqrt{1-\pi^2} - (1-\pi)}{\pi}.$$

Therefore, $\mathcal{W}^o < \mathcal{W}^c$ for all $R \in (R_a/\pi, 2R_a)$.

Q.E.D.

Proof of Corollary 3:

Conditional on $\theta = H$, the probability that both banks bid an amount less than or equals to b is

$$\pi^2(1-\gamma)^2F^2(b),$$

and the probability that only one bank bids an amount less than or equals to b is

$$\pi^2\gamma(1-\gamma)F(b) + 2\pi(1-\pi)(1-\gamma)F(b).$$

Therefore, an H-borrower's expected payoff is

$$\int_{R_a/\pi}^{R}(R-b)\mathrm{d}\left[\pi^2(1-\gamma)^2F^2(b) + \pi^2\gamma(1-\gamma)F(b) + 2\pi(1-\pi)(1-\gamma)F(b)\right].$$

Obviously, since $F(b)$ has the support $[R_a/\pi, R]$, the H-borrower's payoff is strictly positive for any $R \in (R_a/\pi, 2R_a]$.

Q.E.D.

Proof of Proposition 6:

We denote by $\mathcal{B}_i$ the support of bank i's bidding strategy. First, similarly to the symmetric equilibrium, neither bank will bid $\tilde{b} > R$ because such a bid will not be accepted by the borrower. In addition, neither bank will bid $\tilde{b} < R_a/\pi$; otherwise, even if bank i who bids $\tilde{b}$ wins for sure and its financial cost is the lowest one (r_a/π), its expected payoff is

$$V_i(\tilde{b}, H) = \pi(\tilde{b} - r_a/\pi) < R_a - r_a. \tag{35}$$

The rest of the proof then follows a series of lemmas.

Lemma 3. *In equilibrium, neither bank will bid an amount $\tilde{b} \in (R_a/\pi, R)$ with a strictly positive probability.*

Proof of Lemma 3:

Suppose that in equilibrium, bank i bid $\tilde{b} \in (R_a/\pi, R)$ with a strictly positive probability. There are two cases. First, for any $\delta > 0$, $\mathcal{B}_j \cap \left[\tilde{b}, \tilde{b} + \delta\right) \neq \emptyset$. In such a case, consider a possible deviation of bank j from a $b' \in \mathcal{B}_j \cap \left[\tilde{b}, \tilde{b} + \delta\right)$ to $\tilde{b} - \epsilon$, where both $\delta > 0$ and $\epsilon > 0$ are sufficiently close to zero. By such a deviation, bank j's conditional (on winning) payoff is

$$\begin{aligned}
&\lim_{\epsilon \to 0} V_j(\tilde{b} - \epsilon, H) \\
=&\frac{\pi \Pr(\tilde{b} < \beta_i^{oa}(H))}{\pi \Pr(\tilde{b} < \beta_i^{oa}(H)) + (1-\pi)\Pr(s_i = L)}\tilde{b} - r_a \\
>&\frac{\pi \Pr(\tilde{b} \leq \beta_i^{oa}(H))}{\pi \Pr(\tilde{b} \leq \beta_i^{oa}(H)) + (1-\pi)\Pr(s_i = L)}\tilde{b} - r_a \\
=&\lim_{\epsilon \to 0} V_j(\tilde{b} + \delta, H),
\end{aligned}$$

implying that such a deviation is profitable. Here, the inequality is due to the fact that bank i bids $\tilde{b}$ with strictly positive probability. So, in equilibrium, $\mathcal{B}_j \cap \left[\tilde{b}, \tilde{b} - \delta\right)$ must be empty.

However, in the second case where $\mathcal{B}_j \cap \left[\tilde{b}, \tilde{b} - \delta\right) = \emptyset$, it is profitable for bank i to deviate from $\tilde{b}$ to $\tilde{b} + \epsilon$, since this will strictly increase the conditional payoff. Therefore, in equilibrium, neither bank will bid $\tilde{b} \in (R_a/\pi, R)$ with a strictly positive probability.

Q.E.D.

Using a similar argument for the case of $\mathcal{B}_j \cap \left[\tilde{b}, \tilde{b} - \delta\right) = \emptyset$ in the proof of Lemma 3, we have Lemma 4 below.

Lemma 4. *In equilibrium,*

1. *if an open interval (β_1, β_2) is a subset of $\mathcal{B}_i$, it must also be a subset of $\mathcal{B}_j$;*
2. *there is no open interval (β_1, β_2) such that $(\beta_1, \beta_2) \cap \mathcal{B}_i = \emptyset$, and $\inf \mathcal{B}_i < \beta_1 < \beta_2 < \sup \mathcal{B}_i$ (for $i = 1, 2$).*

Lemma 4 implies that the interior set of $\mathcal{B}_i$ and that of $\mathcal{B}_j$ are the same, and there is no "hole" in $\mathcal{B}_i$. Lemma 5 then establishes the upper bound of $\mathcal{B}_i$, applying the intuitive criterion test.

Lemma 5. *In an equilibrium that satisfies the intuitive criterion, $\sup \mathcal{B}_i = \sup \mathcal{B}_j = R$.*

Proof of Lemma 5:

Suppose that $\sup \mathcal{B}_i = \sup \mathcal{B}_j < R$. Then, if bank i deviates to bid $b' \in (\sup \mathcal{B}_i, R)$ and wins the competition, its depositor must believe that bank i receives a good signal. This is the only off-equilibrium path belief that can pass the intuitive criterion test because if bank i receives a bad signal, it will never bid even if it is perceived to receive a good signal.

Then, given the depositor's posterior following the winning bid b', bank i strictly prefers b' to $\sup \mathcal{B}_i$, because the probability of winning the competition is the same and the conditional (on winning) expected payoff is strictly higher. Hence, in an equilibrium that satisfies the intuitive criterion, $\sup \mathcal{B}_i = \sup \mathcal{B}_j = R$.

Q.E.D.

It follows from Lemma 5 that if neither bank bids R with a strictly positive probability, both banks must choose not to bid with probability γ when observing good signals, where γ is defined as in equation (10). This will imply that both banks' equilibrium payoff is $R_a - r_a$, which further implies that the lower bound of banks' bidding strategy support is R_a/π. Then, the equilibrium must be symmetric. Hence, there must be one and only one bank that will bid R with strictly positive probability.

Lemma 6. *Suppose that bank i bids R with probability $\rho > 0$ in equilibrium. Then, bank j, when observe a signal $s_j = H$, must choose not to bid with probability $\gamma > 0$ and so bank j's equilibrium payoff is $V_j(H) = R_a - r_a$. In addition, $\inf \mathcal{B}_j = R_a/\pi$.*

Proof of Lemma 6:

Since bank i bids R with probability $\rho > 0$, bank j will not bid R in equilibrium because of the banking competition: Bank j can deviate to a bid that is strictly less than but sufficiently close to R. On the other hand, since bank i is willing to bid R, the winner's curse implies that bank j must choose not to make an offer to the borrower with a strictly positive probability. Similarly to Proposition 2, the probability of bank j choosing not to bid when observing a good signal must be γ, and bank j's equilibrium payoff must be $R_a - r_a$.

Since the lower bound of $\mathcal{B}_i$ and that of $\mathcal{B}_j$ are the same, for bank j, bidding $\inf \mathcal{B}_j$ (or an amount sufficiently close to $\inf \mathcal{B}_j$) will surely win the competition. (If bank i puts some mass at $\inf \mathcal{B}_i$, Lemma 3 implies that $\inf \mathcal{B}_i = R_a/\pi$. But then, bank j's payoff from bidding arbitrarily close to R_a/π will be strictly less than $R_a - r_a$ due to the winner's curse.) In such a case, bank j's payoff must be also $R_a - r_a$, implying that $\inf \mathcal{B}_j = \inf \mathcal{B}_i = R_a/\pi$.

Q.E.D.

Given Lemma 3 to Lemma 6, the equilibrium characterization will be the same as that of the symmetric equilibrium, except that one bank may put a positive mass at the bid R. Suppose that bank j, when observing a signal $s_j = H$, chooses not to bid with probability χ. Then, $\rho + \chi = \gamma$ because bank i's expected payoff from bidding an amount that is sufficiently close to R must be $R_a - r_a$. This completes the proof of the proposition.

Q.E.D.

Proof of Lemma 2:

The probability that the H-borrower gets funded is

$$\mathcal{P}_H^o = \pi^2(1 - \gamma\chi) + \pi(1 - \pi)(2 - \gamma - \chi),$$

and the probability that the L-borrower gets funded is

$$\mathcal{P}_L^o = (1 - \pi)^2(1 - \gamma\chi) + \pi(1 - \pi)(2 - \gamma - \chi).$$

Given that

$$
\begin{aligned}
&\mathcal{W}^o(\chi)\\
=&\frac{1}{2}\left[\mathcal{P}_H(R-1)+(1-\mathcal{P}_H)(R_a-1)\right]+\frac{1}{2}\left[\mathcal{P}_L(-1)+(1-\mathcal{P}_L)(R_a-1)\right]\\
=&\frac{R_a}{2}\left[\mathcal{P}_H\left(\frac{R}{R_a}-1\right)-\mathcal{P}_L\right]+(R_a-1),
\end{aligned}
$$

we have

$$
\begin{aligned}
&\frac{\mathrm{d}}{\mathrm{d}\chi}\mathcal{W}^o(\chi)\\
=&\frac{R_a}{2}\left[(-\pi^2\gamma-\pi(1-\pi))\left(\frac{R}{R_a}-1\right)+(1-\pi)^2\gamma+\pi(1-\pi)\right]\\
=&0.
\end{aligned}
$$

The last equation is from substituting γ defined in equation (10). Then, since $\mathcal{W}^o(\chi)$ is continuous at $\chi=\gamma$, we have

$$
\mathcal{W}^o(\chi)=\mathcal{W}^o(\gamma),\quad \forall\chi\in[0,\gamma).
$$

Q.E.D.

Proof of Proposition 8:

Similarly to the arguments for the proof of Proposition 6, bank 1 does not make an offer to the borrower when it observes a bad signal. Also, the upper bound of bank 1's bidding strategy support must be R so that the off-equilibrium path belief can satisfy the intuitive criterion. This implies that the upper bound of bank 2's bidding strategy must also be R; otherwise, bank 2 can deviate from its highest bid to R to increase its conditional (on no default) payoff without changing the wining probability.

Since in equilibrium, at least one bank does not put positive mass at R, the winner's curse implies that it must be bank 1 who bid R with probability $\rho>0$, and by bidding R, bank 1's conditional payoff is

$$
\chi\left[\pi(R-r_a)\right]+(1-\chi)(R_a-r_a),
$$

where $\chi>0$ is the probability that bank 2 does not offer the borrower. (If bank 2 always makes an offer, bank 1 will not bid R when observing a good signal, since it will lose for sure.)

Since $\chi > 0$, bank 2's equilibrium payoff must be $R_a - r_a$, which is just its reservation payoff. Then, as bank 2 bids an amount that is sufficiently close to R, its payoff must be

$$\frac{\pi\rho + (1-\pi)}{[\pi\rho + (1-\pi)] + [(1-\pi)\rho + \pi]}(R - r_a) = R_a - r_a.$$

Therefore,

$$\rho = \frac{(R_a - r_a) - (1-\pi)(R - r_a)}{\pi(R - r_a) - (R_a - r_a)}.$$

On the other hand, in equilibrium, bank 2, by bidding the lower bound of its bidding strategy, must win the competition for sure. This implies that the lower bound of both banks' bidding strategies is R_a/π. In addition, neither bank will put a mass at R_a/π: if bank 1 bids R_a/π with positive probability, bank 2 will lose when bidding an amount sufficiently close to or equal to R_a/π, and its conditional (on winning) payoff will be strictly less than $\frac{1}{2}(2R_a - r_a - r_a) < R_a - r_a$; if bank 2 bids R_a/π with positive probability, bank 1 will prefer to bid slightly less than R_a/π to discretely increase its winning probability. Therefore, for bank 1 to be indifferent, χ must satisfy

$$\pi\left(\frac{R_a}{\pi} - r_a\right) = \chi\left[\pi(R - r_a)\right] + (1-\chi)(R_a - r_a),$$

implying that

$$\chi = \frac{(1-\pi)(2\pi - 1)}{\pi(\pi z - 1) + (1-\pi)(2\pi - 1)},$$

where $z = R/R_a \in (1/\pi, 2]$.

Q.E.D.

Proof of Proposition 9:

We focus on a symmetric equilibrium. Similarly to the arguments for the proof of Proposition 2, neither bank bids when observing a bad signal. When they observe a good signal, the intuitive criterion test requires them to bid R as the highest possible bid. Then, when bidding R, bank i's payoff is

$$2\pi(1-\pi)\left[\frac{1}{2}(R - r_a)\right] + \left[\pi^2 + (1-\pi)^2\right](R_a - r_a).$$

Let $\underline{b}$ be the lower bound of the banks' bidding strategy support. Then, when a bank bids $\underline{b}$, it wins the competition for sure. In such a case, its expected payoff is $\pi(\underline{b} - r_a)$.

A bank's indifference condition then implies that

$$\pi(\underline{b} - r_a) = 2\pi(1-\pi)\left[\frac{1}{2}(R - r_a)\right] + \left[\pi^2 + (1-\pi)^2\right](R_a - r_a),$$

which pins down $\underline{b}$.

Therefore, in equilibrium, both banks bid with a support $[R_a/\pi, R]$ when they observe good signals, and neither bank bids when observing a bad signal.

Q.E.D.

Proof of Proposition 10:

Simply algebra implies that

$$\begin{aligned}
& \mathcal{W}^o(r_a) - \mathcal{W}^c(r_a) \\
= \; & \frac{R_a}{2}\left[\left(\left(1-(1-\pi)^2\right) - (1-(1-\pi)\chi)\right)(z-1) - \left(\left(1-\pi^2\right) - (1-\pi\chi)\right)\right] \\
= \; & \frac{R_a}{2}\left[(1-\pi)(\chi-(1-\pi))(z-1) - \pi(\chi-\pi)\right].
\end{aligned}$$

Hence, when $z = 1/\pi$, $\chi = 1$,

$$\mathcal{W}^o(r_a) - \mathcal{W}^c(r_a) = \frac{R_a}{2}(1-\pi)(1-2\pi) < 0,$$

and when $z = 2$, $\chi = 1-\pi$,

$$\mathcal{W}^o(r_a) - \mathcal{W}^c(r_a) = \frac{R_a}{2}\pi(2\pi-1) > 0.$$

Furthermore,

$$\frac{\mathrm{d}}{\mathrm{d}z}\left(\mathcal{W}^o(r_a) - \mathcal{W}^c(r_a)\right) = (1-\pi)\left(\chi-(1-\pi)\right) + \left[(1-\pi)(z-1)-\pi\right]\frac{\mathrm{d}\chi}{\mathrm{d}z} > 0$$

because $\chi > 1-\pi$, and $(1-\pi)(z-1)-\pi \leq (1-\pi)-\pi = 1-2\pi < 0$. Therefore, there exists a unique $\tilde{R} \in (R_a/\pi, 2R_a)$ such that the open banking system leads to higher economic efficiency if and only if $R \in \left(\tilde{R}, 2R_a\right]$.

Q.E.D.

B A Continuum of Borrowers

In the model described in Section 1, we consider one borrower only. A concern about such a model is that if a bank lends to a large number of borrowers, it can have a well-diversified portfolio, which makes deposits risk free. To address this concern, we argue in this appendix that the shock to the "big" borrower in our core model can be viewed as a systematic risk to a group of specific borrowers, most of whom are served by one bank under current banking. This is consistent with the empirical regularity of banking specialization.[10] We show that our results hold in such a scenario.

In particular, we assume that there is a continuum of borrowers in our model. Then, banks can potential diversify away idiosyncratic risks by lending to sufficiently many borrowers. The game lasts for two days. At day 1, bank 1 serves $\alpha \in (0,1)$ fraction of borrowers, while bank 2 serves $1-\alpha$ fraction of borrowers. While collecting the data from the borrowers who they are serving, the banks get to know that there may be a systematic shock to all borrowers at day 2, which will affect depositors' beliefs about bank asset quality and thus bank financial cost. At the end of day 2, each borrower i will generate a cash flow x_i, which obeys the distribution

$$x_i = \begin{cases} R > 1, & \text{with probability } \theta_A \theta_i; \\ 0, & \text{with probability } 1 - \theta_A \theta_i. \end{cases} \tag{36}$$

Here, $\theta_A \in \{0,1\}$ is the systematic risk with $\theta_A = 1$ meaning the negative shock does not arrive, and $\theta_i \in \{0,1\}$ is borrower i's credit quality with $\theta_i = 1$ meaning she having a high credit quality.

To focus on the main mechanism of our paper, we make the following three assumptions. First, at the beginning of day 1, each bank generates a private signal about whether the systematic shock will hit, and the precision of such a private signal increases in the number of borrowers whose data can be observed by the bank. We assume that if bank i has access to the data of α_i measure of borrowers, the precision of its private signal about the systematic shock is $f(\alpha_i)$. Specifically,

$$f(\alpha_i) \begin{cases} = \pi, & \text{if } \alpha_i \in [\bar{\alpha}, 1]\,; \\ \in (0, \pi), & \text{if } \alpha_i \in (1-\bar{\alpha}, \bar{\alpha})\,; \\ = 0, & \text{if } \alpha_i \in [0, 1-\bar{\alpha}]\,, \end{cases} \tag{37}$$

[10] See, for example, Carey et al. (1998), Daniels and Ramirez (2008), Paravisini et al. (2015), De Jonghe et al. (2020), and Giometti and Pietrosanti (2020). Acharya et al. (2006), Tabak et al. (2011), and Beck et al. (2021) further document evidence that bank specialization either does not adversely impact or even reduces bank risk.

where $\bar{\alpha}$ is very close to but strictly less than 1. (Equation (37) is just for simplicity, since our model about current banking is robust to a slightly informed bank 2.) To emphasize bank specialization, we assume that $\alpha > \bar{\alpha}$. Then, under current banking, bank 1's private signal has the precision π, while bank 2's private signal precision is 0. On the other hand, under open banking, both banks access to all borrowers' data, and so both banks' private signal precision will be π.

Second, in line with banks' well-diversified portfolios and to further simplify algebra, we assume that banks generate perfect information information about any individual borrower's credit quality. Therefore, only borrowers with $\theta_i = 1$ can potentially get loans from the bank. So, there will be no idiosyncratic risks in any bank's portfolio. We assume that there is a continuum of borrowers with measure one whose individual credit qualities are high.

Third, we assume that if the bank chooses the risk-free project, the gross deposit interest rate is arbitrarily close to the project's gross rate of return. This is due to bank competition. By this assumption, banks cannot use the net return from the risk-free project to compensate depositors when they lose by lending to some risky borrowers.[11]

With all these assumption, the banks' and their depositors' information structures are exactly same as those in our core model. The players' payoffs are the same. Therefore, our results of our core model hold in the scenario with banks holding well-diversified portfolios.

[11] Alternative, we may assume that the gross deposit interest rate is the same as the project's gross rate of return, but if banks' expected net return is non-positive, banks strictly prefer the risk-free project.

C Ex-ante Efficient Investment

In the model specified in Section 1, we assume that $R \in (R_a/\pi, 2R_a)$. Such a parameter restriction is important for the results derived in the paper. Specifically, only with the assumption that $R > R_a/\pi$, the model can deliver interesting predictions; otherwise, no bank will bid even with a good signal. On the other hand, $R < 2R_a$ implies that it is inefficient for the banking system to fund the borrower ex ante.[12] The latter parameter restriction is sufficient for the depositors' responses to have striking effects on banking competition and resource allocation. In this appendix, we extend our study to the case where it is ex-ante efficient to fund the borrower. That is, we maintain the assumption that $R > 2R_a$ in this section. We also put an upper bound R; otherwise, a bank with a bad signal will bid even if its depositors believe that it observes a bad signal.

We start with the equilibrium characterization under current banking. Differing from the case where lending to the borrower is ex-ante inefficient, when $R > 2R_a$, bank 2 may participate in the competition, even if it has no private signal about the borrower's credit quality. Imagine that bank 2 bids an interest rate b, which helps it win for sure. Then, bank 2's depositor's posterior about the borrower having a high credit quality is $1/2$, and so $r = 2r_a$. Bank 2, on the other hand, has the same posterior belief and so will have the conditional expected payoff

$$\frac{1}{2}\left[b - 2r_a\right] = \frac{1}{2}b - r_a. \tag{38}$$

Therefore, if $b > 2R_a$, such a conditional expected payoff will be greater than $R_a - r_a$; then, bank 2 is willing to bid b. With the assumption that $R > 2R_a$, it is possible that $b > 2R_a$, and bank 2 may participate in the competition in equilibrium.

Proposition 11 shows that for any $R > 2R_a$, there is an equilibrium in which bank 2 participates in the competition with a positive probability.

Proposition 11. *For any $R \in (2R_a, R_a/(1-\pi)]$, under current banking, there is an equilibrium in which bank 1 bids if and only if $s_1 = H$, and bank 2 bids with probability $1-\omega$, where*

$$\omega = \frac{(2\pi - 1)R_a}{\pi \bar{b}^c - R_a}. \tag{39}$$

[12] Such an assumption highlights the banks' roles in resource allocation, since banks' private information becomes more important in this case. Furthermore, in our opinion, because R_a and R are both gross rates, it is reasonable to assume that $R < 2R_a$.

In addition, $\beta_1(H) \in [2R_a, \bar{b}^c]$, and conditional on bidding, $\beta_2 \in [2R_a, \bar{b}^c)$. Here, $\bar{b}^c$ is defined as

$$\bar{b}^c = \min\left\{R, \frac{R_a}{1-\pi}\left(1 - \frac{2\pi - 1}{\pi}\frac{r_a}{R_a}\right)\right\}. \tag{40}$$

Proof of Proposition 11:

We first derive the condition under which bank 1 with $s_1 = L$ will not bid. Suppose that bank 1 with $s_1 = L$ bids $b \leq R$, and it is perceived to observe a good signal. Then, $r = r_a/\pi$. So, a sufficient condition for bank 1 with $s_1 = L$ refraining from bidding is

$$(1-\pi)\left(R - \frac{r_a}{\pi}\right) \leq R_a - r_a,$$

which is equivalent to

$$R \leq \frac{R_a}{1-\pi}\left(1 - \frac{2\pi - 1}{\pi}\frac{r_a}{R_a}\right). \tag{41}$$

Therefore, since $b \leq R$, bank 1 with $s_1 = L$ does not bid when equation (41) holds. On the other hand, when equation (41) does not hold, the highest possible equilibrium bid that bank 1 with $s_1 = H$ may make will be $\frac{R_a}{1-\pi}\left(1 - \frac{2\pi-1}{\pi}\frac{r_a}{R_a}\right)$, since otherwise, bank 1 with $s_1 = L$ can mimic. Hence, $\bar{b} = \min\left\{R, \frac{R_a}{1-\pi}\left(1 - \frac{2\pi-1}{\pi}\frac{r_a}{R_a}\right)\right\}$ is the highest possible equilibrium bid under current banking. (Note that by definition, banks' equilibrium strategies must be decreasing in their signals.)

Similarly to the arguments in Proposition 8, the interior set of the supports of the two banks' bidding strategies must be the same. So, bank 2 must place a positive mass at $b_2 = \infty$; otherwise, bank 1 will lose for sure by bidding $\bar{b}^c$. Then, bank 2's equilibrium payoff will be $R_a - r_a$, implying that the lower bound of banks' bidding strategy supports must be $2R_a$.

Then, bank 1's indifference condition is

$$\pi 2R_a - r_a = \omega(\pi\bar{b}^c - r_a) + (1-\omega)(R_a - r_a),$$

which implies that bank 2 does not bid with probability

$$\omega = \frac{(2\pi - 1)R_a}{\pi\bar{b}^c - R_a}.$$

Q.E.D.

One interesting equilibrium property under current banking is that the lowest equilibrium bid of either bank is always $2R_a$, while the highest bid increases as R increases from $2R_a$ to $\frac{R_a}{1-\pi}\left(1-\frac{2\pi-1}{\pi}\frac{r_a}{R_a}\right)$ and then keeps at $\frac{R_a}{1-\pi}\left(1-\frac{2\pi-1}{\pi}\frac{r_a}{R_a}\right)$ as R increases further. The pattern of the highest equilibrium bid is due to the potential mimicking of bank 1 with $s_1 = L$: When R is very large, bank 1 with $s_1 = H$ will bid up to $\frac{R_a}{1-\pi}\left(1-\frac{2\pi-1}{\pi}\frac{r_a}{R_a}\right)$ to deter such mimicking.

In equation (5), we assume that bank 1's private signal is sufficiently precise; that is, $\pi \geq r_a/R_a$. Corollary 5 shows that if $\pi = r_a/R_a$, bank 1 also deters the competition of bank 2 in equilibrium. (Note that even if π is fixed at r_a/R_a, its range is still $(1/2, 1)$, since we do not set a restriction for r_a/R_a.)

Corollary 5. *When $\pi = r_a/R_a$, under current banking, bank 2 does not bid, and bank 1 will bid (with an amount $2R_a$) if and only if $s_1 = H$.*

Proof of Corollary 5:

When $\pi = r_a/R_a$, $\bar{b}^c \leq 2R_a$. Since bank 1's equilibrium bidding range is $[2R_a, \bar{b}^c]$, bank 1 will bid $2R_a$ if it observes a good signal. If it observes a bad signal, on the other hand, it does not bid, since $r = r_a/(1-\pi)$ otherwise. Also, it follows from equation (39) that when $\pi = r_a/R_a$, the fact that $\bar{b}^c = 2R_a$ implies that $\omega = 1$. That is, bank 2 does not bid in equilibrium.

Q.E.D.

The reason why bank 2 does not bid in Corollary 5 differs from that in Lemma 1. In Lemma 1, the conditional project return is low $R < 2R_a$, the winner's curse, which is exacerbated by the depositor's response, is so severe that bank 2's conditional (on winning) payoff is lower than its reservation value. In contrast, in Corollary 5, the conditional project return is high (R can be very large), but bank 1 with $s_1 = H$ has to bid low so that bank 1 with $s_1 = L$ does not mimic and thus the financial cost can be kept at a low level. As a result, if bank 2 bids, the winning bid will be also low, and so the winner's curse makes its conditional expected payoff lower than its reservation value.

We now turn to the equilibrium characterization under open banking. With a large conditional project return, the effects of the depositors' responses are dominated. In particular, one bank does not need to choose not to bid to compensate the winner's curse to other bank. Therefore, both banks bid if and only they observe good signals, provided that the conditional project return is below a very high bound.

Proposition 12. *For any $R \in [2R_a, R_a/(1-\pi)]$, under open banking, there is a symmetric equilibrium in which both banks bid if and only if they observe good signals. In addition, for $i = 1, 2$, $\beta_i(H) \in \left[\underline{b}^o, \bar{b}^o\right]$, where*

$$\bar{b}^o = \min\left\{R, \left[\left(1 + \left(\frac{\pi}{1-\pi}\right)^2\right) + \left(1 - \left(\frac{\pi}{1-\pi}\right)^2\right)\frac{r_a}{R_a}\right] R_a\right\} \tag{42}$$

$$\underline{b}^o = (1-\pi)\bar{b}^o + \left(\frac{\pi^2 + (1-\pi)^2}{\pi}\right) R_a. \tag{43}$$

Proof of Proposition 12:

We first derive the condition that a bank with a bad signal does not bid. As in the proof of Proposition 2, both banks will bid without a mass point in a symmetric equilibrium. Assume that each bank bids if and only if it observes a good signal. Therefore, by bidding the conditional project return, bank i wins if and only if bank j observes a bad signal. Therefore, if bank i with $s_i = L$ bids R, its' conditional expected payoff is

$$\frac{(1-\pi)^2}{(1-\pi)^2 + \pi^2}\left[R - r\right] = \frac{(1-\pi)^2}{(1-\pi)^2 + \pi^2}\left[R - 2r_a\right].$$

Set such a conditional expected payoff to be less than or equal to $R_a - r_a$, we have

$$R \leq \left[\left(1 + \left(\frac{\pi}{1-\pi}\right)^2\right) + \left(1 - \left(\frac{\pi}{1-\pi}\right)^2\right)\frac{r_a}{R_a}\right] R_a.$$

That is, when the above equation holds, a bank with a bad signal does not bid. Since by definition, a bank's equilibrium strategy is decreasing in its private signal, when observing a good signal, a bank will bid up to $\bar{b}^o$ as defined in equation (42).

Suppose that bank i observes a private signal $s_i = H$. By bidding $\bar{b}^o$, bank i wins if and only if $s_j = L$. Hence, its expected payoff is

$$\begin{aligned} &2\pi(1-\pi)\left[\frac{1}{2}(\bar{b}^o - r)\right] + \left(\pi^2 + (1-\pi)^2\right)(R_a - r_a) \\ &\qquad = \pi(1-\pi)\bar{b}^o + \left(\pi^2 + (1-\pi)^2\right) R_a - r_a. \end{aligned}$$

Let the lowest possible bid bank i will make be $\underline{b}^o$. Then, bidding $\underline{b}^o$, bank i with $s_i = H$ wins for sure. Hence, its expected payoff is

$$\pi(\underline{b}^o - r) = \pi\underline{b}^o - r_a.$$

Then, bank i's indifference condition implies that

$$\underline{b}^o = (1-\pi)\bar{b}^o + \left(\frac{\pi^2 + (1-\pi)^2}{\pi}\right) R_a.$$

Q.E.D.

The upper bound $\bar{b}^o$ defined in equation (42) follows again from the condition under which banks with bad signals do not bid. Such a bound is much larger than $\bar{b}^c$ defined in equation (40).

Corollary 6. *When $\pi = r_a/R_a$, under open banking, for any $R \in [2R_a, R_a/(1-\pi)]$, each bank bids if and only if it observes a good signal about the borrower's credit quality.*

With Proposition 11 and Proposition 12, we are able to compare the resource allocation efficiency under current banking with that under open banking. In particular, under current banking, bank 1 bids if and only if it observes a good signal, while bank 2 bids with probability $1-\omega$. Therefore, the current banking's funding efficiency is $q_H = 1-(1-\pi)\omega$, and its screening efficiency is $(-1)q_L = (-1)(1-\pi\omega)$. On the other hand, under open banking, both banks bid if and only if they observe good signals, the funding efficiency is $\mathcal{P}_H = 1-(1-\pi)^2$, while the screening efficiency is $(-1)\mathcal{P}_L = (-1)(1-\pi^2)$. Hence, the difference between current banking's ex-ante economic efficiency and open banking's ex-ante economic efficiency is

$$\mathcal{W}^o - \mathcal{W}^c = \frac{R_a}{2}\left[(1-\pi)(\omega-(1-\pi))\left(\frac{R}{R_a}-1\right) + \pi(\pi-\omega)\right]. \tag{44}$$

Since the upper bound of the probability that bank 2 bids under current banking depends on the deposit interest rate r_a, we fix $\pi = r_a/R_a$ to simplify the analysis. With such an assumption, $\omega = 1$ for all $R \in [2R_a, R_a/(1-\pi)]$, so $q_H = \pi$ and $q_L = 1-\pi$. Proposition 13 then shows that for any $R \in (2R_a, R_a/(1-\pi)]$, open banking outperforms current banking in terms of ex-ante economic efficiency.

Proposition 13. *For any $R \in (2R_a, R_a/(1-\pi)]$, $\mathcal{W}^o - \mathcal{W}^c > 0$.*

Proof of Proposition 13:

When π is fixed at r_a/R_a, we have

$$\mathcal{W}^o - \mathcal{W}^c = (1-\pi)\pi\left(\frac{R}{R_a}-2\right) > 0$$

for all $R > 2R_a$.

Q.E.D.

Indeed, with the assumption $\pi = r_a/R_a$, the funding efficiency comparison and the screening efficiency comparison are same as in Proposition 5. However, because the conditional project return $R > 2R_a$, the funding efficiency becomes more important in determining the ex-ante economic efficiency. Since open banking has higher funding efficiency when R is large, it outperforms current banking in terms of economic efficiency.

We finally study the borrower's welfare. Surprisingly, with the assumption that $\pi = r_a/R_a$, we find that when banks' private signals are sufficiently precise, that is, r_a is very close to R_a, current banking leads to higher borrower welfare.

Proposition 14. *Fix $\pi = r_a/R_a$. Then, there is a $\hat{\pi} \in (1/2, 1)$. For any $\pi \in (\hat{\pi}, 1)$, there exists $\hat{R} \in (2R_a, R_a/(1-\pi))$, such that when $R \in (\hat{R}, R_a/(1-\pi))$, the borrower has a higher expected payoff under current banking.*

Proof of Proposition 14:

With the assumption $\pi = r_a/R_a$, for any $R \in [2R_a, R_a/(1-\pi)]$, bank 2 does not bid and bank 1 bids $2R_a$ with probability π under current banking. Therefore, the borrower's expected payoff under current banking is

$$\pi(R - 2R_a) \to \left(\frac{\pi}{1-\pi}\right) R_a - 2\pi R_a$$

as R is close to $R_a/(1-\pi)$.

Under open banking, a bank with a good signal charges up to $R \leq R_a/(1-\pi)$. The lower bound that a bank with a good signal will charge is $\frac{\pi+\pi^2+(1-\pi)^2}{\pi} R_a$. From a bank's indifference condition, we derive the CDF of a bank's bid (conditional on that it observes a good signal) as

$$F(b) = \frac{(\pi + \pi^2 + (1-\pi)^2)R_a - \pi b}{(\pi^2 + (1-\pi)^2)R_a - \pi^2 b}.$$

Therefore, the borrower's expected payoff when π is close to 1 and R is close to $R_a/(1-\pi)$ is

$$\begin{aligned} &\left[\pi^2 + 2\pi(1-\pi)\right] \frac{R_a}{1-\pi} - \left[\pi^2 \int_{\underline{b}^o}^{\frac{R_a}{1-\pi}} b \mathrm{d}F^2(b) + 2\pi(1-\pi) \int_{\underline{b}^o}^{\frac{R_a}{1-\pi}} b \mathrm{d}b\right] \\ = &\left[\pi^2 + 2\pi(1-\pi)\right] \frac{R_a}{1-\pi} - 2\pi \int_{\underline{b}^o}^{\frac{R_a}{1-\pi}} (\pi F(b) + (1-\pi)) b \mathrm{d}F(b) \end{aligned}$$

Then, the difference between the borrower's expected payoff under open banking and that under current banking is

$$3\pi R_a - 2\pi \int_{\underline{b}^o}^{\frac{R_a}{1-\pi}} (\pi F(b) + (1-\pi)) b \mathrm{d}F(b).$$

Substituting $F(b)$ and letting $y = \pi^2 b - (\pi^2 + (1-\pi)^2) R_a$, we find that such a difference converges to $-\infty$ as $\pi \to 1$. Therefore, when π is sufficiently large, and R is very close to $R_a/(1-\pi)$, the borrower has higher expected payoff under current banking.

Q.E.D.

Proposition 14 follows from the interaction of several effects. First, when r_a is close to R_a, $\pi = r_a/R_a$ is close to 1, implying that banks' private signals are extremely precise. Then, the conditional project return is potentially very large, since its upper bound $R_a/(1-\pi)$ is unbounded. This means that the H-borrower's expected return is very high. Although under open banking, an H-borrower is more likely to be funded, when banks' private signals are sufficiently precise, her expected return is almost same under open banking and under current banking.

Therefore, which banking system will lead to higher borrower's welfare depends on under which banking system the borrower's expected interest rate is lower. Corollary 5 shows that under current banking, the interest rate the borrower is charged is fixed at $2R_a$. By contrast, Corollary 6 shows that the interest rate the borrower is charged can be very high under open banking. This is so because the severe winner's curse allows banks with good signals to charge very high interest rates. Therefore, when banks have precise private signals, and the conditional project return is high, current banking leads to higher borrower welfare.