Open Banking under Maturity Transformation

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June 20, 2023

Abstract

Open banking is a policy initiative that enables borrowers to share data with any financial institutions. This paper explores impact of open banking on lending market competition and its resulting consequences. In our model, banks compete for underbanked borrowers in common-value auctions and engage in maturity transformation. Under closed banking, the bank with borrower data is an informational monopolist. Under open banking, banks with good signals may refrain from lending. Open banking reduces resource allocation efficiency, narrows bank spread, and enhances financial inclusion. Maturity transformation affects the impact of open banking by preventing banks from transferring risks to their creditors.

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1 Introduction

Open banking, or consumer-directed finance, is a policy innovation that aims to increase lending market competition. Under open banking, banks and other financial intermediaries, such as shadow banks and fintech lenders, provide rights to customers over their data, especially the ability to share data with third parties. The data scope is much richer than periodic statement information for settled banking transactions. It also includes other information, such as payment footprints, which are not shown on periodic statements or portals and so are usually difficult for borrowers to collect and share under the current closed banking regime.[1] Hence, such a new banking ecosystem may potentially break down barriers to competition, because a financial intermediary's competitive advantage nowadays is largely built on its proprietary borrower data. Therefore, as open banking accelerates over the world,[2] it will reshape lending market competition with many data-analytics-based lenders participating.

While open banking is expected to increase lending market competition, there are few formal studies to support such a claim. Then, will lending market necessarily become more competitive when the regime shifts from closed banking to open banking? If yes, is the resulting fierce competition desirable? That is, what are the consequences of the regime shift on resource allocation efficiency, bank financing, and borrower welfare? Also, how does maturity transformation, which is the central role played by financial intermediaries in the modern economy, affect the consequences of such a regime shift?

This paper offers a theoretical analysis of these questions. Since the questions explored touch on key aspects of evaluating a banking policy, in addition to interesting theoretical insights, our study also offers important policy implications. Specifically, the adoption of open banking in many developed countries, including the US and Canada, has been slowed due to concerns about its potential adverse effects. Therefore, by identifying any potential risks associated with open banking, this study can provide valuable support for policy makers, such as the US Consumer Financial Protection Bureau, to develop better regulations before the regime formally changes.

[1] Recent studies, such as Berg et al. (2020), Di Maggio et al. (2022), Ghosh et al. (2022), Nam (2022), and Rishabh (2023) document evidence showing that in many economic scenarios, these alternative data can predict borrower credit quality even better than credit scores do.

[2] Open banking has been adopted in European countries, Australia, and some countries in Asia and South America. In the US, the Consumer Financial Protection Bureau announced a new regulation framework on October 27, 2022 to govern "open banking," implying that open banking is coming to America. In Canada, the Bank of Canada is soliciting opinions about benefits and risks of an open banking system.

Our model is parsimonious yet comprehensive enough to encompass the significant distinctions between open banking and closed banking, as well as the fundamental characteristics of financial intermediaries. First, following the literature on lending market competition (Broecker, 1990; Hauswald and Marquez, 2003, 2006), we consider two financial intermediaries, bank 1 and bank 2, competing for a group of borrowers who are subject to a common shock in a common-value auction.[3] In the event of a positive shock, every borrower receives a positive cash flow, referred to as the ”conditional borrower cash flow.” However, if the shock is negative, borrowers will not receive any cash flow. Although the shock is unknown to all agents, banks can estimate it using their own data-analytic algorithms. These algorithms utilize borrower data as inputs and generate private signals.

In our model, we recognize a close relationship between data and signal, while acknowledging their distinction. A bank's private signal is more precise if it has more borrower data. Even if both banks have access to the same borrower data, their private signals may differ, and these signals will be conditionally independent due to their different data-analytic algorithms. We assume that banks have equally efficient data-analytic algorithms, leading to potentially fierce competition under open banking. Without loss of generality, we assume that bank 1 currently serves all borrowers. So, under closed banking, bank 1 observes an informative private signal, whereas bank 2 does not. By contrast, under open banking, borrowers share their data with bank 2, enabling it to obtain a private signal that is as precise as Bank 1's signal.

Second, our model features a feedback loop between bank financing and bank investment. This feature arises naturally from maturity transformation. During bank debt rollover, banks' creditors base the pricing of banks' short-term debt on their information about bank loan quality. Banks will then internalize the effect of their loans on their financial cost when competing for the borrowers. Such a feedback loop is particularly important when analyzing open banking because the majority of participants are shadow banks, especially fintech lenders, that finance mainly by uninsured short-term debt and actively engage in maturity transformation (Jiang et al., 2020). Even small traditional banks' financial costs also respond to their investments (Chen et al., 2021).

[3]The common shock is essentially the systematic risk of issuing loans to the group of borrowers. For instance, mortgage borrowers in San Francisco could be exposed to a common shock if tech layoffs were to occur. This assumption is necessary for examining the role of maturity transformation with bank creditors being more concerned about the bank's overall loan quality than individual borrower credit quality. For the sake of simplicity, we disregard each borrower's idiosyncratic risk.

Third, we focus on a situation where granting loans to borrowers without new information is inefficient.[4] This group of borrowers is the main target of the open banking policy, as they usually have limited credit histories and so are easily held up by relationship banks. As highlighted by a World Bank report (Plaitakis and Staschen, 2020), it is important to study how open banking can benefit individuals who are underbanked or unbanked.

We first characterize how the regime shift from closed banking to open banking reshapes the lending market competition. Under closed banking, in equilibrium, bank 2 refrains from issuing loans, and so bank 1 becomes an informational monopolist. By contrast, under open banking, there is a unique symmetric equilibrium in which both banks may make competitive offers when they observe good signals. However, even with a good signal, a bank refrains from making offers with a positive probability. Importantly, when the conditional cash flow is sufficiently small, such a probability is close to zero. Therefore, as the regime shifts from closed banking to open banking, the expected number of banks that serve the borrowers reduces from one to almost zero; as a result, measured by the number of competitors, the lending market competition decreases.[5]

The equilibrium lending market competition arises from the ex-ante inefficient borrowers and banks' maturity transformation. On the one hand, because of ex-ante inefficient borrowers, banks issue loans only if they receive positive new information about the common shock, which includes banks' own private signals and potential winner's curse. A winner's curse arises because the bank's success in the competition suggests that its opponent's private signal is likely to be bad.[6] Under closed banking, bank 2 does not have a private signal, so it never participates in the competition, while bank 1 surely bids when observing a good signal because there is no winner's curse imposed on it. Under open banking, in a symmetric equilibrium, a bank refrains from making loan offers with a positive probability when observing a good signal to reduce their opponent's winner's curse. This is because a bank's good signal could be offset by the

[4]We also analyze the case that it is ex-ante efficient to fund the borrowers in Appendix C for a comparison. Such an analysis also supplements other studies of lending market competition that focus on positive NPV projects, such as Broecker (1990) and Hauswald and Marquez (2003, 2006).

[5]We notice that the number of banks that may serve the borrowers is just one measure of lending market competition. Indeed, measured by the loan interest rate or the banking system profit, the lending market is more competitive when the regime shifts from closed banking to open banking.

[6]Recently, Beyhaghi et al. (2023) provide empirical evidence showing the significance of winner's curse in the corporate loan market.

winner's curse, which would result in the bank refraining from issuing loans at all.

On the other hand, in our model, maturity transformation is also a determinant of the equilibrium lending market competition. This is because a bank's creditors consider the bank's loan quality when demanding an interest rate. As a result, banks cannot transfer risks to their creditors through maturity transformation, which would allow them to offer loans to ex-ante inefficient borrowers at lower financial costs.[7]

To gain a better understanding of the role of maturity transformation in lending market competition, we analyze a benchmark scenario with fixed bank financing costs that resembles traditional banks relying on insured deposits. We observe that under closed banking, bank 1 bids when it observes a good signal, while bank 2 also bids with a probability that increases with the conditional borrower cash flow. In open banking, both banks bid when they observe good signals. Our findings suggest that the shift from open banking to closed banking would increase competition in the lending market, even in terms of the number of available banks, if maturity transformation is absent.

After examining the behavior of banks under both closed and open banking policies, we identify an economic risk associated with the adoption of open banking, namely a reduction in the efficiency of resource allocation. Consider a low borrower conditional cash flow first. while bank 1 makes an informed decision under closed banking, both banks under open banking refrain from issuing loans with an extremely high probability, indicating poor functioning of the banking system; as a result, open banking underperforms in this case. On the other extreme, when the conditional borrower cash flow is high (where lending remains inefficient ex ante), banks under open banking become too aggressive and issue loans almost certainly when observing good signals. In such a case, it is much more likely that loans are issued when a bad common shock hits, so open banking also underperforms.

Maturity transformation is also an important factor that affects the efficiency of resource allocation of the banking systems. In a scenario where banks' financial costs remain constant, open banking outperforms closed banking when the conditional borrower cash flow is relatively high. This is because bank 2 will bid blindly under closed banking where it has the ability to shift risks to its creditors. Therefore, the loan issuance is more likely to be an informative decision under open banking than under closed bank-

[7] Although there are situations where banks cannot shift risks, such as when they lend their own funds, we believe that maturity transformation is an essential aspect of financial intermediation. Therefore, it deserves a comprehensive theoretical examination.

ing, implying that open banking can allocate resources more efficiently.

In addition to resource allocation efficiency, the adoption of open banking has significant implications for bank financing. Under closed banking, bank 1 charges borrowers monopoly pricing at the conditional cash flow. However, under open banking, the winning bank that charges borrowers at the conditional cash flow is likely to face a winner's curse. This implies a higher credit risk to the winning bank's creditors, leading to increased financial costs. This occurs because both banks have private signals under open banking. As a result, open banking leads to a narrowed bank spread.

Finally, the regime shift from closed banking to open banking has a significant impact on borrower welfare and financial inclusion. Under closed banking, bank 1 can extract all borrower surplus by offering a monopoly price, leading to zero ex-post payoffs for borrowers when the common shock is positive. By contrast, banks may offer loan interest rates strictly lower than the conditional borrower cash flow, which leads to strictly positive expected payoffs for borrowers when the common shock is positive and they are funded. Therefore, open banking improves borrower welfare and helps promote financial inclusion.

Contributions to the Literature Our paper is among the first ones evaluating open banking.[8] In a contemporaneous paper, He et al. (2023) 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 FinTech 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. Babina et al. (2022) estimate a structural model and show that open banking increases Fintech companies' entry but potentially reduces ex-ante information production. Complementing these studies, we focus on the effects of adopting open banking on lending market competition, resource allocation efficiency, bank financing, and financial inclusion. We also theoretically discuss how maturity transformation, the central role played by most financial

[8]Open banking is about data sharing among financial institutions, and so our paper is also related to the papers that investigate financial institutions' incentives to share borrower data (Pagano and Jappelli, 1993; Bouckaert and Degryse, 2006). However, since open banking features the borrowers' rights to control and share their data, the strategic environments in these papers differ significantly from ours.

intermediaries, affects the consequences of the banking regime change. Importantly, we shows that open banking may lead to low resource allocation efficiency, identifying a potential risk of open banking that policy makers need to craft rules for.

Our paper is related to a recent literature on economics of data. Farboodi et al. (2019) argue that data is generated in economic activity, increases firm efficiency, and is a valuable asset. Farboodi and Veldkemp (2019) show that data, as an intangible asset, is an important reason for "free" apps and firm size divergence. We add to this literature that data is the input of information generation function. In our model, same borrower data lead to different private signals under open banking since banks use different data-analytic algorithms.

The literature on economics of data also studies relation between data and firm market power. Jarsulic (2019) points out that the unequal accumulation of data is responsible for a decline in competition. Kirpalani and Philippon (2020) show that consumer sharing data with platform gives more market power to the platform, which can reduce consumer welfare. Eeckhout and Veldkemp (2022) craft a model in which a data-rich firm captures a larger market share. Cong and Mayer (2022) also prove that data feedback may concentrate market power. In our model, when the regime shifts from closed banking to open banking, borrowers sharing data may effectively reduce the number of banks that serve the borrowers. Also, even if open banking may lead to more fierce lending market competition, it may lead to inefficient resource allocation.

Our paper belongs to the literature on lending market competition. In particular, our model about bank competition under closed banking follows Hauswald and Marquez (2003), and the analysis of such a model contributes to the literature on relationship finance (Sharpe, 1990; Rajan, 1992; von Thadden, 2004) where banks with information advantage can hold up borrowers and extract information rents. Similarly, our model about bank competition under open banking follows Broecker (1990). The existing studies assume ex-ante efficient borrowers and do not compare the case where bank private signals have different qualities and the case where banks are equally informed. We contribute to this strand of literature by focusing on ex-ante inefficient borrowers who are the target of the open banking policy. With such an assumption, we show that open banking (the case with two equally informed banks) may underperform closed banking (the case with one informed bank and one uninformed bank) in resource allocation.

Finally, our paper also contributes to the discussion about how bank investment interacts with bank financing. Cordella and Yeyati (2002), Allen et al. (2011), Dell'Ariccia et al. (2014), and Cordella et al. (2018) assume that a bank is protected by limited liability, so its creditors will exercise due diligence (by analyzing bank investment) when lending money to the bank. In our model, bank financing is similar to these papers, but bank loan quality is largely affected by winner's curse caused by banks' competition and their heterogeneous information.

2 A Model of Lending Market

We consider an economy with two financial intermediaries competing for a continuum of homogeneous borrowers with measure one. While we call the financial intermediaries "banks" for simplicity, they are mainly referred to as shadow banks and fintech companies. The economy lasts for three days, indexed by $t = 1, 2, 3$.

Borrowers At the beginning of day 1, each borrower needs to borrow \$1 for consumption or her small business, and the banks are the only financing source. Each borrower may obtain a cash flow x at day 3, which depends on a common shock.[9] Specifically, denoting by $\theta \in \{L, H\}$ the common shock, we assume that the day-3 cash flow is

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

Without losing any generality, we assume that $L = 0$ and $H = 1$. Hence, when $\theta = L$, a *negative* shock hits, and any borrower will get a zero cash flow; when $\theta = H$, a *positive* shock arrives, and each borrower obtains a positive cash flow R. Since each borrower tries to borrow \$1 at day 1, R can be interpreted as both an amount or a gross return. We assume that the day-3 cash flow is observable and contractible, and borrowers have limited liabilities. So borrowers will default if a negative common shock hits, and they will pay back up to R if the common shock is positive. We therefore call R the "conditional cash flow."

We assume that all agents in our model share an equal common prior about the common shock; that is, $\Pr(\theta = H) = 1/2$. In our model, the borrowers are lack of data and expertise to estimate the common shock, so a borrower's individual behavior does not reveal any information about the common shock.

[9] For simplicity, we assume that the banks either have perfect information or have no information about each individual borrower's idiosyncratic shock.

Bank Investments Both banks can serve the borrowers. They are, however, heterogeneous in the information about the common shock θ. In particular, bank 1 is serving all borrowers at the beginning of the game. This assumption is a direct implication of banking specialization, an empirical pattern that is documented by Carey et al. (1998); Daniels and Ramirez (2008); Paravisini et al. (2015); De Jonghe et al. (2020); Giometti and Pietrosanti (2020). Therefore, bank 1 can access to all borrower data and then use its data-analytic algorithm to generate a private signal s_1 about the common shock. 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 measures the efficiency of bank 1's data-analytic algorithm. We assume that bank 2 has an equally efficient data-analytic algorithm; however, if it does not obtain any borrower data, it cannot estimate the common shock.

At day 1, each bank chooses between funding the borrowers or investing the \$1 in a risk-free project. Both investment options are long-term in the sense that banks will not get payments until day 3. Suppose that the risk-free project will generate a cash flow $R_a \in (0, R)$ at day 3. We focus on the case that[10]

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

On the one hand, $R < 2R_a$ implies that it is inefficient to issue loans to the borrowers ex ante. We focus on this case because open banking policy targets underbanked or even unbanked borrowers who have limited credit histories and low wealth. On the other hand, $R > R_a/\pi$ suggests that without drawing any inference about the other bank's signal, it is efficient for a bank with a good signal to lend to all borrowers.

Banking Competition At day 1, both banks simultaneously make offers to all borrowers based on their own signals about the common shock. For tractability, we assume that a bank treats all homogeneous borrowers equally; that is, it either does not lend to any

[10] We analyze the case where $R \geq 2R_a$ in Appendix C. In such a case, the feedback loop between bank financial cost and bank investment caused by maturity transformation does not play a critical role. However, we find that when the conditional cash flow 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. It turns out that the equilibrium bids of banks with good signals are much lower under closed 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.

borrower or lend to all borrowers at the same interest rate. This assumption is aligned with Fair Lending laws that ensure financial institutions to provide fair and uniform services and credit decisions.

Denote by $b_i \in [1, R]$ the gross rate quoted by bank i and by $b_i = \infty$ bank i's decision not issue loans. Observing the bids from both banks, the borrowers choose bank i if $b_i < b_j$. In a tie case of $b_i = b_j < \infty$, the borrowers jointly chooses bank i with probability $1/2$, and if and only if $b_i = b_j = \infty$, the borrowers are 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 borrowers are funded, ι and $\hat{b}$ will be revealed to bank ι's creditors. The losing bank will invest in the risk-free project, and its bid is never revealed to any agent except the borrowers.

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 creditors' responses to the winning bid. If bank ι wins the competition, its loan rate is revealed to its short-term creditor when rolling over short-term debt, who will then demand a new short-term debt interest rate. 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 impact the winning bank's creditor's belief and thus the winning bank's financial cost. Intuitively, bank ι's short-term creditor will demand a higher interest rate because of the credit risk. The banks take the effect of their loans on their financial costs into account when making offers to the borrowers.

Bank Financial Costs Each bank finances \$1 from a competitive short-term creditor. For simplicity, we assume that the short-term debt interest rate from day 1 to day 2 is zero. The bank needs to roll over such short-term debt at day 2, with a promised gross payment $r \in (1, R)$ at day 3. The short-term creditors are uninsured, and the banks have also limited liabilities. So the banks will pay their creditors up to r at day 3 if they can. Obviously, if a bank gets a zero cash flow at day 3, its creditor will get a zero payment.

The most important feature of our model is that the promised gross return r at day 3 is endogenous. In particular, at day 2, each bank's potential short-term creditors can observe whether the bank is lending to the borrowers or investing in the risk-free project. If a bank invests in the risk-free project, the payment it promises to its new short-term creditor will be $r = r_a \in (1, R_a)$ where r_a is exogenous. Hence, by investing in the risk-free project, the bank's payoff will be $R_a - r_a > 0$, which will prevent banks with bad signals from bidding to gamble for resurrection. After bank ι lends to the borrowers, on the other hand, its potential short-term creditors at day 1 will form a posterior ζ about the common shock based on the bank's quote to the borrower. Because the creditors are competitive, the winning bank's promised payment at day 3 will be $r = r_a/\zeta$.

Banking Systems The difference between open banking and closed banking in our model is whether bank 2 can obtain borrower data and generate a private signal. Specifically, under closed banking, bank 1 possesses and controls borrower data, and so bank 2 cannot estimate the common shock beyond the prior. By contrast, under open banking, borrowers have the right to freely share their data. Therefore, when they shop rates, they will share data with bank 2, and so bank 2 will observe a private signal s_2. Provided that both banks' data-analytic algorithms are equally efficient, s_2 and s_1 have the same precision and are conditionally independent. In particular, we assume that bank 2's signal is

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

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

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.

3 Lending Market Competition

In this section, we analyze how the regime shift from closed banking to open banking reshapes the lending market competition. We achieve this goal by characterizing banks' equilibrium bidding strategies under both closed banking and open banking in Section 3.1 and Section 3.2, respectively. In Section 3.3, we demonstrate how maturity transformation affects the effect of the regime shift on lending market competition by analyzing a benchmark where bank financial costs are fixed.

3.1 Closed Banking

We start with the lending market competition under closed banking, where bank 2 is uninformed about the common shock. The main result in this subsection is that for any conditional cash flow $R \in \left(\frac{R_a}{\pi}, 2R_a\right)$, bank 1 is an informational monopolist.

We first characterize bank 2's equilibrium bidding strategy. Lemma 1 shows that bank 2 never participates in the competition.

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

Bank 2 is not joining the competition because of low conditional borrower cash flow and maturity transformation. The former limits bank 2's ability to generate revenue from issuing loans, while the latter hampers its ability to maintain low financial costs by transferring risks to short-term creditors.

Because of the low conditional borrower cash flow, a bank will make loan offers only if its posterior belief about a positive common shock is sufficiently high, which requires that the bank receives positive new information. Under closed banking, bank 2 is uninformed, so it will not observe a good signal. In addition, if bank 2 successfully makes offers to the borrowers, it may be subject to winner's curse, since its success in the competition suggests that bank 1's private signal is likely bad. Therefore, bank 2 cannot grant loans because it does not have sufficient positive information about the common shock.

Then, bank 2 can only makes loan offers under closed banking if it is able to finance at a low costs. This could occur when bank 2 transfers some risks to its short-term creditors, which is prevented by maturity transformation. Indeed, if bank 2 issues loans to the borrowers, its short-term creditors will also face winner's curse and thus demand a high short-term debt interest rate.

Lemma 1 implies that bank 1 is the only bank that may potentially serve the borrowers. To simplify the analysis, we assume that banks' private signals (when they have borrower data) are 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 borrowers if it observes a bad signal, even if it is perceived to receive a good signal by its short-term creditors. We then characterize the unique equilibrium that satisfies intuitive criterion under closed 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 creditors when bank 1 lends to the borrowers 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, 2006). In particular, the unique equilibrium under closed banking is a pure-strategy equilibrium in which bank 2 does not participate in the competition, and bank 1 is engaging in monopoly pricing. As we argued, the difference arises from low conditional borrower cash flow and bank maturity transformation.

3.2 Open Banking

We now study the lending market competition under open banking. In such a banking regime, borrowers can share their data with bank 2, so both banks will generate equally precise and conditionally independent private signals. Since both banks observe private signals with the same quality, we focus on a symmetric equilibrium in this subsection and leave the discussion of asymmetric equilibria in Appendix B.

Proposition 2 characterizes a unique symmetric equilibrium that satisfies intuitive criterion.[11]

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*

$$\beta_i^o(H) = \begin{cases} \infty, & \textit{with probability } \gamma; \\ b \in \left[\frac{R_a}{\pi}, R\right], & \textit{with conditional CDF } F(b). \end{cases} \tag{8}$$

Here,

$$\gamma = \frac{(1-\pi)\pi\left(2 - \frac{R}{R_a}\right)}{\left(\frac{R}{R_a} - 1\right)\pi^2 - (1-\pi)^2}, \tag{9}$$

$$F(b) = \frac{1}{1-\gamma}\left[1 - \frac{\pi(1-\pi)\frac{2R_a - b}{R_a}}{\pi^2\frac{b-R_a}{R_a} - (1-\pi)^2}\right]. \tag{10}$$

If bank ι wins the competition, its short-term creditor's belief is

$$\zeta(\hat{b}, \iota) = \begin{cases} \pi, & \forall \hat{b} \in \left[1, \frac{R_a}{\pi}\right); \\ \frac{\pi\left(\pi\Omega(\hat{b}) + (1-\pi)\right)}{\pi\left(\pi\Omega(\hat{b}) + (1-\pi)\right) + (1-\pi)\left((1-\pi)\Omega(\hat{b}) + \pi\right)}, & \forall \hat{b} \in \left[\frac{R_a}{\pi}, R\right], \end{cases} \tag{11}$$

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 $s_j = H$.

An important property of the equilibrium characterized in Proposition 2 is that both banks refrain from making offers to the borrowers even if they observe good signals. This property also arises from low conditional borrower cash flow and maturity transformation.

[11] We apply intuitive criterion for equilibrium refinement because a bank's loan decision signals its private signal about the common shock. Indeed, there is an equilibrium in which banks with good signals bid over $[R_a/\pi, \tilde{b}]$, where $\tilde{b} < R$. Such an equilibrium needs the support of the creditors' 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'.

Under open banking, each bank receives good private signal about the common shock with precision π, but is also exposed to a winner's curse. Then, whether a bank with a good private signal makes loan offers depends on the severity of the winner's curse. Assuming banks always bid when they receive good signals, issuing loans with the highest interest rate indicates the opponent bank received a bad signal.[12] As a result, the winner's curse offsets the advantage of the good signal, leading the winning bank to base its decision on prior information and not make loan offers.

On the other hand, similar to bank 2 under closed banking, banks under open banking are also unable to transfer risks to their short-term creditors due to maturity transformation. This means that issuing loans with low financial costs is impossible since all relevant information, including the bank's private signal inferred from its bid and the impact of the winner's curse, will be priced into the bank's short-term debt.

Therefore, to mitigate their opponent's winner's curse, banks adopt a strategy of refraining from making loan offers with a probability of $\gamma > 0$ (defined in (9)) in equilibrium. Then, even if a bank offers loans with the highest interest rate, there is still a chance that their opponent has observed a good signal but chooses not to bid. This relieves the winner's curse for a bank and allows its good private signal to dominate, making banks indifferent and able to issue loans in equilibrium.

The mixing behavior of banks in deciding whether to make loan offers or not can be purified by external economic factors not captured in our model. One such factor is a bank's long-run planning, which affects the bank's loan decision only when it is indifferent based on profit-cost analysis. Suppose that the probability of a group of borrowers not matching a bank's long-run planning is γ. In this case, a bank with an expected payoff equal to the risk-free project return will make loan offers with probability γ, purifying the mixed strategy in equilibrium.

One comparative static of interest is the relationship between the probability that a bank with a good private signal refrains from making loan offers (γ) and the conditional borrower cash flow (R). Equation (9) shows that γ is strictly decreasing in R. This comparative static arises not because a higher conditional cash flow brings a bank a higher expected payoff, but because a bank needs to increase its opponent's winner's curse in equilibrium. As the conditional cash flow increases from R_a/π to $2R_a$, a bank

[12] In a symmetric equilibrium, there will be a highest equilibrium loan interest rate, which will have no mass in banks' bidding strategies; otherwise, a bank may deviate to an offer that is slightly lower and increase the winning probability by a non-trivial amount.

with a good signal is more likely to make offers to borrowers. However, the increased winner's curse not only reduces the bank's expected profit but also increases its financial costs due to maturity transformation. Specifically, as R increases, a bank's conditional expected payoff increases, and 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, requiring a lower probability that the other bank refrains from bidding when receiving a good signal (i.e., γ must decrease).

Simple algebra implies that when the conditional borrower cash flow is extremely low and close to R_a/π, the probability that banks make loan offers, γ, approaches one. That is, in this scenario, banks are almost certain to refrain from issuing loans. This result has important implications for lending market competition. Under closed banking, where the informed bank is an informational monopolist and makes loan offers based on its private signal, the system may function even when the conditional borrower cash flow is very low. However, under open banking, both banks have access to the same borrower data, but the probability that either bank makes loan offers becomes negligible when the conditional cash flow is close to R_a/π. Thus, the entire banking system becomes ineffective in such cases. If lending market competition is measured by the expected number of banks that can serve borrowers, then the shift from closed banking to open banking may reduce competition in certain cases.

3.3 The Role of Maturity Transformation

As previously explained, maturity transformation affects the effect of the regime shift from closed banking to open banking on lending market competition because bank short-term creditors price bank short-term debt fairly based on their information about bank loan quality. As a result, banks cannot finance at low costs by transferring risks to their creditors. This leads to the nonparticipation of the uninformed bank under closed banking and the positive probability of a bank with a good private signal refraining from making loan offers under open banking.

To further illustrate the impact of maturity transformation, we consider a benchmark in this subsection where we assume that banks' financial costs are fixed at r_a. In this setting, banks rely on insured deposits to finance their activities. Thus, at day 3, each bank is obligated to pay its depositors r_a if it does not default; in case of default, the depositors receive payment from the insurance company. To simplify the algebra, we assume that the lower bound of R is $R_a/\pi = 2R_a - r_a$, and hence $r_a/R_a = (2\pi - 1)/\pi$.[13]

We find that there is a unique equilibrium under closed banking. In this equilibrium, bank 1 offers loans to borrowers whenever it receives a good signal but does not make a bid when it receives a bad signal. In contrast, bank 2 bids with a positive probability in equilibrium, which differs from the scenario where the bank short-term creditors respond to the bank's investment decision.

Proposition 3. *Suppose that the banks' financial costs are fixed at r_a. Under closed 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 loan offers to the borrowers when observing a good signal but does not do so when observing a bad signal. Bank 2 will make loan offers to the borrowers too with a probability $1 - \chi$, where*

$$\chi = \frac{(1-\pi)(2\pi - 1)}{\pi\,(\pi z - 1) + (1-\pi)(2\pi - 1)}. \tag{12}$$

The difference between Proposition 3 and Proposition 1 is that bank 2 may participate in the competition even if it cannot access to borrower data. This is because when bank 2's creditors do not respond to its investment, its financial cost will stay at a low level. Hence, bank 2 is facing a less severe 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.

We now turn to open banking with insured deposits. We find that in equilibrium, both banks will surely make offers to the borrowers if they observe good signals.

Proposition 4. *Suppose that the banks' financial costs are fixed at r_a. Under open banking, 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.*

Proposition 4 also follows from the fact that a bank can transfer risks to its creditors when they do not respond to bank loans. Therefore, even if a bank's good private signal is offset by the winner's curse imposed on it, its expected profit will be higher than that from investing in the risk-free project.

Comparing Proposition 4 with Proposition 3, we find that open banking will surely increase lending market competition when bank creditors do not respond to bank investment, even if we measure competition by the expected number of banks serving

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

borrowers. This result holds for any conditional borrower cash flow and thus differs significantly from the case under maturity transformation.

4 Consequences of Regime Shift

Now that we have analyzed banks' behavior under closed banking and open banking, we proceed to examine the consequences of the regime shift from closed to open banking. We will focus on three key aspects. Firstly, in Section 4.1, we will investigate the banking system's resource allocation efficiency, which is a crucial factor in contributing to the overall economy. Additionally, we will explore how the effect of the regime shift on resource allocation efficiency is influenced by maturity transformation. Next, in Section 4.2, we will examine how open banking affects bank financing. As bank financing is connected to financial market stability, if banks are unable to roll over their short-term debt, bank runs may occur. Finally, in Section 4.3, we will study whether the adoption of open banking policy can enhance borrower welfare. This study will be particularly relevant for ex-ante inefficient borrowers who are underbanked or unbanked, and so it may provide insight into whether open banking can promote financial inclusion.

4.1 Resource Allocation Efficiency

We define a banking system's resource allocation efficiency as the ex-ante expected cash flow the banking system generates. The resource allocation efficiency can be decomposed into a banking system's funding efficiency and its screening efficiency. The former refers to the probability that the borrowers are funded when the common shock is positive, while the latter is about the probability that the banking system does not issue loans when the common shock is negative. The resource allocation efficiency is then the weighted average of the funding efficiency and the screening efficiency.

We start with funding efficiency. Under closed banking, bank 2 will not issue loans, while bank 1 issue loans if and only if it observes a good private signal. Then, conditional a positive common shock $\theta = H$, the borrowers will be funded with probability π, because bank 1 observes a good signal with probability π. Note that under closed banking, the banking system's funding efficiency is independent of the conditional borrower cash flow.

Different from closed banking, open banking's funding efficiency increases in the conditional borrower cash flow. Denote by $\mathcal{P}_H^o(R)$ the probability that the borrowers are funded under open banking when the common shock is positive. Then, if and only if $\mathcal{P}_H^o(R) \geq \pi$, open banking outperforms closed banking in funding efficiency.

Since under open banking, a bank never makes an offer to the borrowers 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 offers loans to the borrowers, and the second term is the probability that exactly one bank receives a good signal and it lends to the borrowers.

We find that when the common shock is positive, open banking may not serve the borrowers better than closed banking when the conditional cash flow R is low. This is formally stated in Proposition 5 and illustrated in Figure 1.

Proposition 5. *Suppose that under open banking, the agents play a symmetric equilibrium. There is a $R_H \in (R_a/\pi, 2R_a)$ such that open banking outperforms closed banking in funding efficiency, if and only if $R \geq R_H$.*

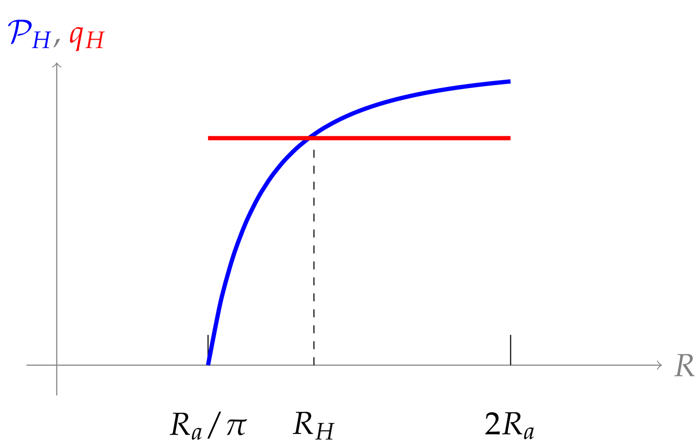

Figure 1: Comparison between open banking and closed banking in terms of funding efficiency. $\mathcal{P}_H$ is the probability of the borrowers getting funded under open banking and q_H is that under closed banking, conditional on $\theta = H$.

Proposition 5 follows Proposition 2. When R is closed to R_a/π, γ is almost one, suggesting that it is almost impossible for the borrowers to get funded under open banking even if the common shock is positive. Hence, in such a case, open banking underperforms closed banking in funding efficiency. On the other extreme, when R is approaching $2R_a$, γ converges to zero, implying that both banks will surely make loan offers when they observe good signals. In such a case, conditional on a positive common shock, the borrowers are more likely to be funded, since the probability of at least one of the two banks observing a good signal under open banking is greater than the probability of bank 1 observing a good signal. Then, equation (9) implies that as R increases, each bank is more likely to make loan offers, and so the whole banking system is more likely to fund the borrowers conditional on a positive shock. As a result, there is a cutoff of the conditional borrower cash flow, R_H, such that open banking outperforms closed banking in funding efficiency if and only if $R \geq R_H$.

The effect of the regime shift on screening efficiency is precisely the inverse of that on funding efficiency. Open banking outperforms for low conditional borrower cash flows but underperforms for high conditional borrower cash flows. We denote by $\mathcal{P}_L^o$ and q_L the probabilities that the borrowers are funded conditional on a negative shock under open banking and under closed banking, respectively. Then, open banking outperforms closed banking if and only if $\mathcal{P}_L^o \leq q_L$. Conditional on a negative common shock $\theta = L$, under closed banking, the borrowers are funded only when bank 1 receives a good signal. Hence, $q_L = 1 - \pi$. Under open banking, the borrowers are funded when there is at least one bank that receives a good signal, so

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

Proposition 6 shows that open banking has higher screening efficiency than closed banking if and only if the conditional borrower cash flow is below a threshold R_L. This is illustrated in Figure 2.

Proposition 6. *Suppose that under open banking, the agents play a symmetric equilibrium. Then, there is a $R_L \in (R_a/\pi, 2R_a)$ such that open banking outperforms closed banking in screening efficiency if and only if $R \leq R_L$.*

We then investigate the effect of adopting open banking on the resource allocation efficiency by combining funding efficiency and screening efficiency and taking into account the conditional borrower cash flow and the risk-free project return. Denote by

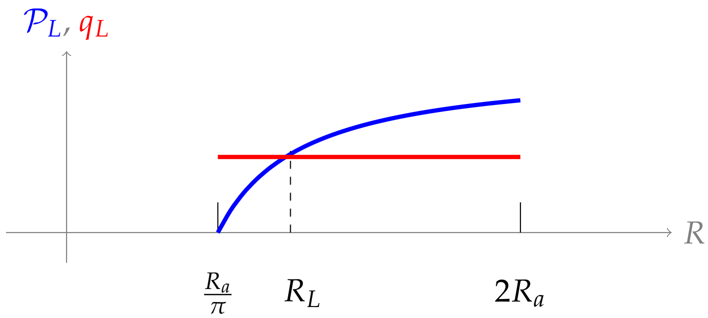

Figure 2: Comparison between open banking and closed banking in terms of screening efficiency. $\mathcal{P}_L$ is the probability of the borrowers getting funded under open banking and q_L is that under closed banking, conditional on $\theta = L$.

$\mathcal{W}^c(R)$ and $\mathcal{W}^o(R)$ the resource allocation efficiency of closed banking and open banking, respectively. We obtain

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

$$\begin{aligned}\mathcal{W}^o(R) =& \frac{1}{2}\left[\mathcal{P}_H^o\left(R-1\right)+\left(1-\mathcal{P}_H^o\right)\left(R_a-1\right)\right]\\&+\frac{1}{2}\left[\mathcal{P}_L^o\left(-1\right)+\left(1-\mathcal{P}_L^o\right)\left(R_a-1\right)\right].\end{aligned} \tag{16}$$

Proposition 7 shows that in terms of the ex-ante economic efficiency, open banking underperforms closed banking.

Proposition 7. *Suppose that the agents play the symmetric equilibrium characterized in Proposition 2.*[14] *For any $R \in (R_a/\pi, 2R_a)$, open banking leads to lower ex-ante economic efficiency than closed banking.*

Proposition 7 can be explained as follows. Because of low conditional borrower cash flow, it is inefficient to issue loans based on the prior information. As a result, under open banking where two banks observe equally informative private signals, it is inefficient to issue loans if one bank receives a good signal but the other bank receives a bad signal, because the two private signals cancel out each other in predicting the common shock. However, in this scenario, the bank with a good signal may issue loans with a

[14] We show in Appendix B that when banks play an asymmetric equilibrium under open banking, the open banking's resource allocation efficiency does not change. Therefore, although multiple asymmetric equilibria under open banking exist, the result presented in Proposition 7 is robust.

large probability in equilibrium, implying that the open banking system is too aggressive in issuing loans, which reduces resource allocation efficiency.

The aforementioned reasoning, however, has limitations in its applicability to cases involving relatively low conditional borrower cash flows. In these scenarios, open banking is highly cautious and issues loans with a very low probability. Nevertheless, open banking still underperforms due to a significant trade-off in informed funding efficiency. Specifically, banks reject loan applications despite of their good signals. One example is when the conditional borrower cash flow, R, is very close to the lower bound R_a/π. Equation (9) shows that the probability of banks refraining from making loan offers is almost one. Therefore, the banking system is experiencing a malfunction, and even in instances of effective funding where both banks receive positive signals, the opportunity will be overlooked.

The comparison between open banking and closed banking in terms of economic efficiency is illustrated in Figure 3. Obviously, the difference between the ex-ante economic efficiency under open banking and that under closed banking, $\mathcal{W}^o(R) - \mathcal{W}^c(R)$, is non-monotonic: It first decreases and then increases in the conditional cash flow R.

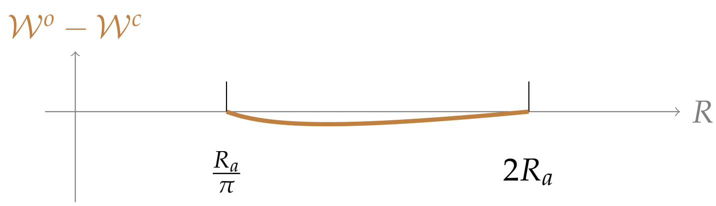

Figure 3: Comparison between open banking and closed banking in terms of ex-ante economic efficiency.

One interesting question is how maturity transformation affects the resource allocation efficiency of adopting open banking. Proposition 8 answers this question.

Proposition 8. *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 $R \in (\tilde{R}, 2R_a]$, open banking outperforms closed banking in resource allocation efficiency.*

The economic setting described in Proposition 8 is the case when banks finance mainly by insured deposits; as a result, their financial costs are fixed at r_a, and they do not actively engage in maturity transformation. In such a framework, Proposition 3 implies that under closed banking, the resource allocation efficiency is

$$\mathcal{W}^c(R|r_a) = \frac{1}{2}\left[q_H^a(R-1) + (1-q_H^a)(R_a-1)\right] + \frac{1}{2}\left[q_L^a(-1) + (1-q_L^a)(R_a-1)\right], \quad (17)$$

where

$$q_H^a = 1-(1-\pi)\chi, \quad (18)$$
$$q_L^a = 1-\pi\chi, \quad (19)$$

and χ is defined in equation (12).

Similarly, Proposition 4 implies that under open banking, the resource allocation efficiency is

$$\mathcal{W}^o(R|r_a) = \frac{1}{2}\left[\mathcal{P}_H^a(R-1) + (1-\mathcal{P}_H^a)(R_a-1)\right] + \frac{1}{2}\left[\mathcal{P}_L^a(-1) + (1-\mathcal{P}_L^a)(R_a-1)\right], \quad (20)$$

where

$$\mathcal{P}_H^a = 1-(1-\pi)^2, \quad (21)$$
$$\mathcal{P}_L^a = 1-\pi^2. \quad (22)$$

The difference between the resource allocation efficiencies under closed banking and under open banking when bank financial costs are fixed at r_a is

$$\mathcal{W}^o(R|r_a) - \mathcal{W}^c(R|r_a) = \frac{R_a}{2}\left[(\mathcal{P}_H^a - q_H)\,(\frac{R}{R_a}-1) + (q_L^a - \mathcal{P}_L)\right]. \quad (23)$$

When R is closed to R_a/π, $\mathcal{W}^o(R|r_a) - \mathcal{W}^c(R|r_a) < 0$, implying that when the conditional borrower cash flow is low, open banking has lower resource allocation efficiency. However, when R is close to $2R_a$, $\mathcal{W}^o(R|r_a) - \mathcal{W}^c(R|r_a) > 0$, meaning that open banking will lead to higher resource allocation efficiency when the conditional cash flow is high. Further algebra shows that $\mathcal{W}^o(R|r_a) - \mathcal{W}^c(R|r_a)$ is strictly increasing, which implies Proposition 8. The consequence of adopting open banking policy on resource allocation efficiency when bank financial cost is fixed at r_a is illustrated in Figure 4.

Comparison between Figure 4 with Figure 3 shows the significant role played by maturity transformation. In particular, when bank financial cost is fixed at r_a, banks can transfer risks to their creditors. Hence, under open banking, both banks will make loan offers if and only if they observe good signals, so open banking behaves very aggressively. However, closed banking behaves even more aggressively. The uninformed

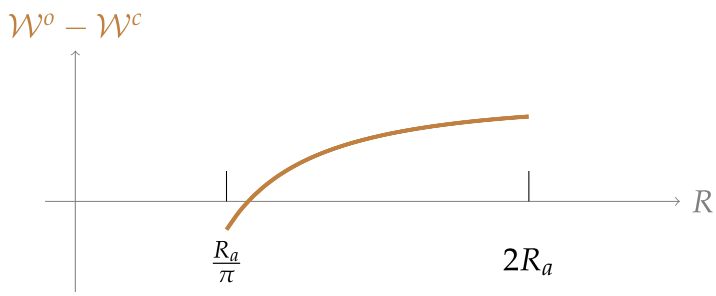

Figure 4: Comparison between open banking and closed banking in terms of economic efficiency when r is fixed at r_a.

bank may issue loans blindly. As a result, except the case where the conditional borrower cash flow is so low that the uninformed bank makes loan offers with a very low probability, open banking outperforms closed banking in resource allocation efficiency when bank financial cost is fixed at r_a.

4.2 Bank Financing

Another intriguing outcome of adopting open banking pertains to bank financing. The pricing of a bank's short-term debt under maturity transformation will now take into account all the available information accessible to the bank's short-term creditors. This information encompasses the private signal of the bank, as indicated by its loan offer, as well as the possibility of a winner's curse.

Under closed banking, the only equilibrium bank loan interest rate is R, the conditional borrower cash flow. This occurs when bank 1 receives a good signal. Under open banking, there is a continuum of possible equilibrium bank loan interest rates, which include R. We, therefore, consider the case that the equilibrium bank loan interest rate is also R under open banking. In this way, we eliminate the effect of loan interest rate on bank financing cost.

Under closed banking, when bank 1 issues loans with an interest rate R, its short-term creditors perceive that the bank has received a positive signal. This is due to the bank's separation strategy, as defined in equation (6). As bank 2 does not have any private information, it does not offer loans, causing bank 1's creditors to make inferences about the common shock based solely on bank 1's loan decision. Hence, during bank 1's debt rollover, the creditors' posterior belief about a positive common shock is π, and therefore, the fair interest rate for the short-term debt of bank 1 is r_a/π.

Under open banking, if bank 1 issues loans with an interest rate R in equilibrium, its creditors perceive that it has received a positive signal. However, they will also infer that bank 2 has also received a positive signal with probability $\gamma/(\gamma+1)$, where γ is defined in equation (9). This inference is a result of bank 2's bidding strategy, as described in equation (8). Corollary 1 then determines bank 1's financial cost in this scenario, which reveals that open banking will result in higher financial costs for the bank.

Corollary 1. *Under open banking, if a bank issues loans with a loan interest rate R in equilibrium, its financial cost is*

$$r(R) = \frac{r_a}{\zeta(R)}, \tag{24}$$

where

$$\zeta(R) = \frac{\gamma}{1+\gamma}\left[\pi^2 + (1-\pi)^2\right] + \frac{1}{1+\gamma}\left[2\pi(1-\pi)\right]. \tag{25}$$

Since $\zeta(R) < \pi$, $r(R) > r_a/\pi$, implying that fixed bank loan interest rate at R, open banking increases bank financial cost and narrows bank spread.

Corollary 1 is based on the idea that open banking can lead to a winner's curse for bank 1's creditors. If bank 1 offers loans with an interest rate R, its creditors perceive that it receives a good signal about the common shock because it would not offer loans otherwise. Under closed banking, where bank 2 has no private signal and thus is not involved, bank 1's creditors face no winner's curse. However, under open banking, bank 2 can access borrower data and obtain a private signal. If bank 1 wins the competition, its creditors infer that bank 2 is likely to receive a bad signal, leading to a winner's curse. This situation makes bank 1's creditors concerned about the quality of bank 1's loans and demand a higher short-term debt interest rate.

4.3 Financial Inclusion

We now examine the impact of regime shift from closed banking to open banking on the welfare of borrowers. Since we focus on underbanked or unbanked borrowers, we can gain insights into how open banking affects financial inclusion.

Proposition 1 demonstrates that under closed banking, bank 1 is the only lender that may issue loans in equilibrium. Also, when bank 1 receives a good signal and issues loans, the loan interest rate of R, so bank 1 receives all of the borrower surplus, which leads to each borrower receiving a zero payoff. Additionally, if either the common shock is negative or the borrowers are not funded, they also receive zero payoffs. As borrower welfare is zero in all possible cases, the ex-ante borrower welfare is also zero.

On the other hand, Proposition 2 highlights that under open banking, banks with good signals are likely to offer loans with interest rates that are strictly lower than the conditional borrower cash flow. As a result, if the borrowers are funded, their payoffs will be strictly positive, leading to positive borrower welfare.

Corollary 2 then summarizes the comparison borrower welfare under closed banking with that under open banking.

Corollary 2. *The regime shift from closed banking to open banking increases borrower welfare and thus improve financial inclusion.*

5 Conclusion

Open banking enables borrowers to freely share their data with any financial institution they choose. This new banking ecosystem is anticipated to boost lending market competition significantly. To theoretically examine how open banking transforms lending market competition and its impact on resource allocation efficiency, bank financing, and borrower welfare, we develop a model in this paper.

Our model comprises multiple elements that correspond with the key feature of open banking policy. Firstly, while borrowers have the liberty to share their data with all financial intermediaries, banks cannot share their signals. Consequently, banks solely rely on conditional independent private signals and so are susceptible to winner's curses. Secondly, banks in our model are mainly shadow banks, especially fintech lenders, that finance by uninsured short-term debt and actively engage in maturity transformation. As a result, banks are unable to transfer risks and will be accountable for the effects of their loans on their financing costs. Thirdly, issuing loans is inefficient ex ante, which indicates that borrowers are initially underbanked or unbanked. Consequently, the study of the impact of open banking on borrower welfare provides insight into how open banking influences financial inclusion.

In equilibrium, under closed banking, the informed bank is an informational monopolist, and under open banking, banks refrain from lending even if they observe good signals. Specifically, when the conditional borrower cash flow is relatively low, the average number of banks that could potentially serve borrowers is even less than one. This implies that, in certain scenarios, open banking may not result in an increase in lending market competition, as measured by the expected number of banks.

The impact of open banking on lending market competition is influenced by two factors: low conditional borrower cash flow and bank maturity transformation. When the borrower cash flow is low, banks with good signals may refrain from making loan offers to reduce their opponents' winner's curse. Due to maturity transformation, banks cannot maintain low financial costs by transferring risks to their creditors. We also find that when banks finance through insured deposits, open banking always results in more fierce lending market competition.

Surprisingly, the shift from closed banking to open banking reduces the resource allocation efficiency of the banking system. Additionally, bank spread narrows since bank creditors also face winner's curse and demand a higher short-term debt interest rate. Despite the less efficient resource allocation, open banking increases borrower welfare and enhances financial inclusion.

Beyond its theoretical contributions, our paper has significant policy implications. We identify a scenario where open banking may lead to inefficient resource allocation, which represents a potential risk associated with adopting open banking. Given that the primary role of a banking system is to allocate resources/credits in the modern economy, it is critical to identify potential policy risks before they are formally implemented. Policymakers can develop regulations that minimize risks while maintaining the benefits of new policies.

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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 creditor'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 creditor does not update his belief about the common shock. 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 closed banking.

Q.E.D.

Proof of Proposition 1:

We first verify that bank 1's strategy profile in equation (6) and its creditor'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 creditor should believe that bank 1 receives the signal $s_1 = H$. Hence, under closed banking, 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 (10) 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 common shock 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 (11). 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

$$\begin{aligned} & V_i\left(\frac{R_a}{\pi}, H\right) \\ = \; & \frac{\pi\left[\pi\left(1 - \frac{\rho}{2}\right) + (1-\pi)\right]}{\pi\left[\pi\left(1 - \frac{\rho}{2}\right) + (1-\pi)\right] + (1-\pi)\left[(1-\pi)\left(1 - \frac{\rho}{2}\right) + \pi\right]}\left(\frac{R_a}{\pi}\right) - r_a \\ < \; & R_a - r_a. \end{aligned} \tag{26}$$

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 creditor 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

$$V_i(\bar{b}, H) = \frac{1}{2}\left(\bar{b} - 2r_a\right) \leq \frac{1}{2}R - r_a < R_a - r_a. \tag{27}$$

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 creditor 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

$$V_i(\underline{b}, H) = \pi\left(\underline{b} - \frac{r_a}{\pi}\right) = R_a - r_a. \tag{28}$$

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:

Similarly to the arguments for the proof of Proposition 9, 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

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

where $\chi > 0$ is the probability that bank 2 does not offers the borrowers. (If bank 2 always makes offers, 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 4:

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 5:

According to equation (13), the probability that conditional on $\theta = H$, open banking serves the borrowers with a conditional cash flow $R \in [R_a/\pi, 2R_a]$ is

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

It then follows from equation (9) 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 open banking serves the borrower equals the probability that closed banking serves the borrower. Since γ is strictly decreasing in R, we characterize γ_H, which equalizes $\mathcal{P}_H^o = \pi$. We get

$$\gamma_H = \frac{\sqrt{1-\pi} - (1-\pi)}{\pi} = \frac{\sqrt{1-\pi}}{1+\sqrt{1-\pi}}, \tag{29}$$

which in turn determines R_H by equation (9).

Q.E.D.

Proof of Proposition 6:

By equation (14), when $\theta = L$, the probability that open banking serving the borrowers with a conditional cash flow $R \in [R_a/\pi, 2R_a]$ is

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

Recall that under closed banking, the borrowers are funded with probability $1-\pi$. Therefore, open banking identifies a negative common shock better than closed banking 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 open banking 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

$$\gamma_L = \frac{\sqrt{\pi} - \pi}{1-\pi} = \frac{\sqrt{\pi}}{1+\sqrt{\pi}}, \tag{30}$$

which in turn determines R_L by equation (9).

Q.E.D.

Proof of Proposition 7:

It follows from equations (15) and (16) that the difference between the ex-ante economic efficiency of open banking and that of closed banking is

$$\mathcal{W}^o - \mathcal{W}^c = \frac{R_a}{2}\left[(\mathcal{P}_H^o - \pi)\, z + (1 - \mathcal{P}_H^o - \mathcal{P}_L^o)\right], \tag{31}$$

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 open banking 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

$$\begin{aligned}\frac{\mathrm{d}}{\mathrm{dz}}\left(\mathcal{W}^o - \mathcal{W}^c\right) = \frac{R_a}{2}\Bigg[&\Big(\pi^2(1-\gamma^2) + 2\pi(1-\pi)(1-\gamma) - \pi\Big) \\ &+ \frac{\mathrm{d}\gamma}{\mathrm{dz}}\left(\frac{\mathrm{d}\mathcal{P}_H^o}{\mathrm{d}\gamma} z - \frac{\mathrm{d}\mathcal{P}_H^o}{\mathrm{d}\gamma} - \frac{\mathrm{d}\mathcal{P}_L^o}{\mathrm{d}\gamma}\right)\Bigg].\end{aligned} \tag{32}$$

Substituting $\mathcal{P}_H^o$, $\mathcal{P}_L^o$, and γ into equation (32), 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

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

Then, as $z \to (1/\pi)^+$, $\gamma \to 1$, $\mathrm{d}(\mathcal{W}^o - \mathcal{W}^c)/\mathrm{dz} < 0$; as $z \to 2^-$, $\gamma \to 0$, $\mathrm{d}(\mathcal{W}^o - \mathcal{W}^c)/\mathrm{dz} > 0$. Therefore, if and only if there is a unique $\hat{\gamma} \in (0,1)$ such that $\mathrm{d}(\mathcal{W}^o - \mathcal{W}^c)/\mathrm{dz} = 0$, $\mathcal{W}^o - \mathcal{W}^c < 0$ 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 Proposition 8:

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

Q.E.D.

Proof of Corollary 2:

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, when $\theta = H$, the borrowers' expected payoffs are

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

Obviously, since $F(b)$ has the support $[R_a/\pi, R]$, the borrowers' payoffs are strictly positive for any $R \in (R_a/\pi, 2R_a]$.

Q.E.D.

B Asymmetric Equilibria under Open Banking

In Section 4.1, we study the open banking's ex-ante economic efficiency under the assumption that agents are playing the unique symmetric equilibrium that satisfies the intuitive criterion. In this appendix, we extend our analysis by allowing banks to employ asymmetric bidding strategies in equilibrium and study whether open banking can outperform closed banking in ex-ante economic efficiency in an asymmetric equilibrium.

We find that the model has a continuum of asymmetric equilibria, which are characterized in Proposition 9 below.

Proposition 9. *Under open banking, for any $R \in (R_a/\pi, 2R_a)$, there is an asymmetric equilibrium. In equilibrium, $\beta_1^{oa}(L) = b_2^{oa}(L) = \infty$,*

$$\beta_i^{oa}(H) = \begin{cases} \infty, & \textit{with probability } \gamma; \\ b \in \left[\frac{R_a}{\pi}, R\right), & \textit{with conditional CDF } F(b), \end{cases} \tag{33}$$

and

$$\beta_j^{oa}(H) = \begin{cases} \infty, & \textit{with probability } \chi \geq 0; \\ R, & \textit{with probability } \rho > 0; \\ b \in \left[\frac{R_a}{\pi}, R\right), & \textit{with conditional CDF } F(b). \end{cases} \tag{34}$$

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

$$\zeta(\hat{b}, i) = \begin{cases} \pi, & \forall \hat{b} \in \left[1, \frac{R_a}{\pi}\right); \\ \frac{\pi\left(\pi\Omega(\hat{b})+(1-\pi)\right)}{\pi\left(\pi\Omega(\hat{b})+(1-\pi)\right)+(1-\pi)\left((1-\pi)\Omega(\hat{b})+\pi\right)}, & \forall \hat{b} \in \left[\frac{R_a}{\pi}, R\right), \end{cases} \tag{35}$$

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

$$\zeta(\hat{b}, j) = \begin{cases} \pi, & \forall \hat{b} \in \left[1, \frac{R_a}{\pi}\right); \\ \frac{\pi\left(\pi\Omega(\hat{b})+(1-\pi)\right)}{\pi\left(\pi\Omega(\hat{b})+(1-\pi)\right)+(1-\pi)\left((1-\pi)\Omega(\hat{b})+\pi\right)}, & \forall \hat{b} \in \left[\frac{R_a}{\pi}, R\right); \\ \frac{\pi(\pi\gamma+(1-\pi))}{\pi(\pi\gamma+(1-\pi))+(1-\pi)((1-\pi)\gamma+\pi)}, & \textit{if } \hat{b} = L. \end{cases} \tag{36}$$

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. In the proof of Proposition 9, we show that this is an equilibrium, and both banks' expected payoffs are just their reservation value.

Proof of Proposition 9:

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 borrowers. 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

$$V_i(\tilde{b}, H) = \pi(\tilde{b} - r_a/\pi) < R_a - r_a. \tag{37}$$

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

Lemma 2. *In equilibrium, neither bank will bid an amount $\tilde{b} \in (R_a/\pi, R)$ with a strictly positive probability.*

Proof of Lemma 2:

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 $\delta > 0$, $\mathcal{B}_j \cap [\tilde{b}, \tilde{b} + \delta) \neq \emptyset$. In such a case, consider a possible deviation of bank j from a $b' \in \mathcal{B}_j \cap [\tilde{b}, \tilde{b} + \delta)$ 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 2, we have Lemma 3 below.

Lemma 3. *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 3 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 4 then establishes the upper bound of $\mathcal{B}_i$, applying the intuitive criterion test.

Lemma 4. *In an equilibrium that satisfies the intuitive criterion,* $\sup \mathcal{B}_i = \sup \mathcal{B}_j = R$.

Proof of Lemma 4:

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 creditor 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 creditor'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 4 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 (9). This will imply that both banks' equilibrium payoffs are $R_a - r_a$, 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 5. *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 5:

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 loan offers to the borrowers 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 2 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 2 to Lemma 5, 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.

We now analyze the open banking's economic efficiency, assuming that the agents are playing an asymmetric equilibrium characterized in Proposition 9. Lemma 6 shows that the ex-ante economic efficiency of open banking is independent of how bank j divides the mass γ between $b_j = R$ and $b_j = \infty$.

Lemma 6. *Suppose that the agents are playing an asymmetric equilibrium characterized in Proposition 9 with a $\chi \in [0, \gamma)$. For any $\chi \in [0, \gamma)$, $\mathcal{W}^o(\chi) = \mathcal{W}^o(\gamma)$.*

Proof of Lemma 6:

When $\theta = H$, the probability that the borrowers get funded is

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

Similarly, when $\theta = L$, the probability that the borrowers get funded is

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

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 (9). 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.

Lemma 6 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 6 and Proposition 7 directly imply that ex ante, open banking underperforms closed banking in terms of economic efficiency, even if banks are allowed to employ asymmetric strategies in equilibrium.

Proposition 10. *For any* $R \in (R_a/\pi, 2R_a)$*, open banking underperforms closed banking in terms of ex-ante economic efficiency. This result is robust across all equilibria under open banking that satisfy the intuitive criterion.*

We also find that the equilibrium selection (the symmetric equilibrium or an asymmetric equilibrium) under open banking does not matter for borrower surplus. Suppose that bank i does not lend to the borrowers, and bank j observes a signal $s_j = H$. Then, if $b_j = \infty$, the borrowers are not funded and get zero payoffs, while if $b_j = R$, the borrowers' payoffs are also zero even if they are funded by bank j because bank j will get all the conditional cash flow. Therefore, allowing banks to play asymmetric strategies in equilibrium will not affect the borrowers' expected payoffs.

Corollary 3. *Under open banking, the borrowers' expected payoffs are constant across all equilibria that satisfy the intuitive criterion and are strictly greater than that under closed banking.*

C Ex-ante Efficient Investment

In the model specified in Section 2, 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.[15] The latter parameter restriction is sufficient for the creditors' 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 borrowers. 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 creditors believe that it observes a bad signal.

We start with the equilibrium characterization under closed banking. Differing from the case where lending to the borrowers is ex-ante inefficient, when $R > 2R_a$, bank 2 may participate in the competition, even if it has no private signal about the common shock. Imagine that bank 2 bids an interest rate b, which helps it win for sure. Then, bank 2's creditor's posterior about the common shock 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 closed 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*

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

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

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

[15]Such an assumption highlights the banks' roles in resource allocation, since banks' private information becomes more important in this case.

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 $b \le R$, 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

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

which is equivalent to

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

Therefore, since $b \le R$, 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 closed banking. (Note that by definition, banks' equilibrium strategies must be decreasing in their signals.)

Similarly to the arguments in Proposition 3, 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 closed 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 4 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 4. *When $\pi = r_a/R_a$, under closed 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 4:

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 4 differs from that in Lemma 1. In Lemma 1, the conditional cash flow is low $R < 2R_a$, the winner's curse, which is exacerbated by the creditor's response, is so severe that bank 2's conditional (on winning) payoff is lower than its reservation value. In contrast, in Corollary 4, the conditional cash flow 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 cash flow, the effects of the creditors' responses are dominated. In particular, one bank does not need to choose not to bid to compensate for the winner's curse to other bank. Therefore, both banks bid if and only they observe good signals, provided that the conditional cash flow 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*

$i = 1, 2$, $\beta_i(H) \in [\underline{b}^o, \bar{b}^o]$, *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 cash flow, 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

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

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

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

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 5. *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 closed banking with that under open banking. In particular, under closed banking, bank 1 bids if and only if it observes a good signal, while bank 2 bids with probability $1-\omega$. Therefore, the closed 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 closed 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 closed banking depends on r_a, the short-term debt interest rate when it invests in the risk-free project, 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 closed 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 7. 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 closed 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, closed 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 closed 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 closed banking. Therefore, the borrower's expected payoff under closed 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 closed 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 closed 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 cash flow is potentially very large, since its upper bound $R_a/(1-\pi)$ is unbounded. This means that the borrowers' expected payoffs are very high when $\theta=H$. Although under open banking, the borrowers are more likely to be funded, when banks' private signals are sufficiently precise, her expected return is almost same under open banking and under closed banking.

Therefore, which banking system will lead to higher borrower welfare depends on under which banking system the borrower's expected interest rate is lower. Corollary 4 shows that under closed banking, the interest rate the borrowers are charged is fixed at $2R_a$. By contrast, Corollary 5 shows that the interest rate that the borrowers are 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 cash flow is high, closed banking leads to higher borrower welfare.