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Theoretical and Empirical Essays in the Economics of Banking

Essais théoriques et empiriques en Économie bancaire

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Avertissement

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Résumé :

Cette thèse étudie, d'un point de vue théorique ou empirique, les conséquences sur la concurrence bancaire et sur le bien-être de trois changements récents dans l'industrie bancaire. Le premier chapitre s'intéresse aux effets des politiques de sauvetage public, lorsque les emprunteurs supportent des coûts de changements de banque. La protection de l'État intensifie la concurrence ex ante si elle garantit un accès suffisant aux liquidités. Cependant, le sauvetage peut être indésirable ex post, car la survie de concurrents et les coûts de changements permettent une discrimination par les prix source d'inefficacités dans l'allocation du crédit. Le second chapitre étudie l'accès au crédit des entreprises françaises suite à la fermeture de leur agence bancaire. Après deux ans, ces entreprises détiennent 6% de plus de crédit à cause de la fermeture. Cet effet opère à la fois dans la nouvelle agence et auprès d'agences concurrentes, mais il n'a lieu que dans des communes bien dotées en agences. Le troisième chapitre porte sur les incitations des banques à externaliser leurs systèmes de paiement sur le cloud, en présence de risque cyber. Le risque cyber peut rendre l'externalisation souhaitable. Il peut aussi limiter, ou au contraire renforcer, les incitations des banques à trop externaliser, en raison de défaillances dans leurs relations verticales avec le cloud et avec leurs déposants. Accroître les responsabilités civiles envers les déposants, ou définir le périmètre de responsabilité de chaque acteur en cas d'incident, peut limiter ces défaillances.

Descripteurs: concurrence bancaire, effets de réseau, coûts de changement, agence bancaire, sauvetage public, externalisation, risque cyber

Abstract:

This dissertation consists of theoretical and empirical studies on the consequences of three recent changes in the banking industry on banking competition and welfare. The first chapter examines the effects of bailout policies when borrowers face switching costs. The government protection strenghtens competition ex ante if it guarantees a sufficient liquidity support to banks. However, bailouts may not be welfare-improving ex post, because the survival of competing banks and switching costs enable banks to price-discriminate, which generates inefficiencies in the allocation of credit. The second chapter studies the access to credit of French firms which experienced a closure of their bank branch. After two years, these borrowers hold 6% more credit because of the closure. This effect is supplied by the receiving branch as well as by competing branches, but it only applies in areas with dense branch networks. The third chapter focuses on banks' incentives to outsource their payment systems to a cloud service provider, when cyber-risk exists. Outsourcing may become welfare-improving because of cyber-risk. Cyber-risk can also limit or increase banks' incentives to over-outsource, depending on the failures in the vertical relationships of banks with the cloud service provider and with their depositors. Increasing firms' liability to depositors, or setting their perimeter of responsibility before cyber incidents occur, may alleviate these failures.

Keywords: banking competition, network effects, switching costs, bank branch, bailout, outsourcing, cyber risk

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General Introduction

Mensch, bezahle deine Schulden, Lang ist ja die Lebensbahn,
Und du muszt noch manchmal borgen, Wie du es so oft gethan.[1]
—H. Heine, Buch der Lieder

The ability of financial intermediaries to channel savings into productive investments is a fundamental issue in economics. Among financial intermediaries, banks appear to be key players due to their ability to provide liquidity to all depositors and to develop close relationships with a diverse pool of borrowers. Their screening technology, their size, and their regulatory environment enable them to provide credit to firms when capital markets cannot. Thereby, these specificities are a source of market power for banks with respect to other financial intermediaries and to competing banks. Aside from implicit public support and regulatory constrains, the production of soft information on borrowers and the management of complex information systems generate strong barriers to entry, and limit the competition among banks. Therefore, market power in banking appears to be to some extent a natural by-product of these banks' specificities.

Recent trends in the financial industry question the boundaries of banks' specificities, and they redefine banks' market power. This revision comes from three fronts. First, mergers and public support to the banking industry following the financial crisis of 2007-2008 shed light on the competitive distortions of public intervention, and they called for a stronger scrutiny over banks' sources of rent. As a consequence, supervision authorities became more concerned about banks' transparency, consumer protection and market concentration, with the ambition to limit banks' misconduct on retail markets and too-big-to-fail situations.[2] Second, transformations of the banking environment challenged the importance of activities traditionally performed by banks. The generalization of mobile

[1] Homme, paie tes dettes. Le chemin de la vie est long, Et maintes fois encore tu prendras à crédit, Comme tu l'as déjà fait si souvent.

[2] Inquiries of competition authorities on the banking sector can be traced back before the financial crisis, with heterogeneous concerns across countries. Schematically, US authorities focused on consequences of deregulation and mergers, while EU authorities study barriers to an European market integration. The UK Office of Fair Trading stood out by considering market failures in retail banking (Vives, 2016).

and internet banking weakened the role of branches networks, and the implementation of modern data analytics circumvent the need to collect extensive "soft" (i.e., non-measurable) information on credit applicants. Finally, outside the banking sector, the development of new technologies stimulates the entry of fintech firms and bigtech companies, which offer new or more efficient services in a variety of sectors previously monopolized by banks. While it remains unclear if these new services will substitute or complement banks' activities, the entry of these new players questions the extent of banks' singularity, as they generate new usages and new risks for financial data.

This dissertation studies the impact of some of these changes in the banking industry on banks' strategies and on consumers' welfare. Each article is centered around a specific change in the banking industry (change in bailout policies, branch closure, and data outsourcing), and it studies its consequences on the relationship between banks and their consumers. In this introduction, we first aim to explain why information production on borrowers represent a major source of market power for banks. We provide a selective review of the literature on this topic, with a focus on theoretical results. Then, we discuss how recent technological and regulatory innovations reshape the role of information collection and banking competition.

1 Information on borrowers & banking competition

Information production as a bank specificity

In many contexts, investors are prevented from making loans to valuable projects, because they face information asymmetry with respect to borrowers. By producing information on borrowers, banks can alleviate the asymmetric information problem, and credit can be channeled from investors to borrowers.

First, investors cannot observe at no cost if their money was ultimately used for profitable investments. Thus, borrowers have strong incentives to "shirk" (Holmström and Tirole, 1987), i.e., to declare that their investment was not profitable and to pocket the actual profit from their investments. This asymmetry of information with respect to borrowers demands monitoring from investors, in order to identify borrowers' ability to pay. However, when multiple investors are needed to finance a loan, investors are likely to free-ride when monitoring of projects is required, or they may duplicate monitoring actions.[3] By acting on behalf of investors, diversified banks ("delegated monitors") represent an efficient design, because they solve the free-riding problem faced by investors and they can only report aggregate returns trustfully (Diamond, 1984).

Second, banks also benefit from a better technology than other financial actors to

[3] Alternatively, investors can set penalties on non-paying borrowers, but they may not be dissuasive, and they impose undue costs on non-profitable projects.

distinguish bad borrowers from profitable projects, before a loan is granted. The expertise in the information production, called screening, represents a valuable service to investors, but it faces two important challenges to be profitable for an information producer (Leland and Pyle, 1977). First, the information producer faces a reliability issue, because it cannot guarantee investors that it performed a diligent investigation. In addition, it faces an appropriability issue, because its ratings can be easily resold by informed investors. Banks solve these issues by lending on behalf of investors, such that they do not need to disclose the information. Also, they are incentivized to perform a thorough screening by issuing securities on borrowers, or by reaping all lending profit above the deposit rate.

Information and banks' market power

Asymmetric information between banks and borrowers shapes competition on credit markets. Stemming from the common value bidding theory (Milgrom and Weber, 1982), this literature highlights that the presence of information asymmetries between banks and with respect to borrowers hurdles competition, and limits banks' incentives to undercut the price of its competitors. As banks cannot perfectly discriminate good borrowers from bad ones during the application process, and borrowers can apply for credit to many banks, setting a lower price generates two effects on a bank's profit. Similar to standard competition in prices, a first effect is to enable the bank to attract all borrowers. However, this also enables the winning bank to grant credit only to borrowers it considers creditworthy. This generates externalities on the other banks in the form of adverse selection, as these banks now will only attract borrowers rejected by the undercutting bank, and they should increase their own interest rates. When banks have access to the same information on borrowers, these externalities imply that prices become strategic substitutes, and standard Bertrand competition admits no equilibrium in pure strategies (e.g., Broecker, 1990). This limits banks' incentive to undercut prices, without fully eliminating them.

A main consequence of information asymmetries is that if a bank has superior information on borrowers, it benefits from information rents. A bank may have an informational advantage over other banks because it has lower screening costs (Hauswald and Marquez, 2006), or because it already established a relationship with some borrowers (Sharpe, 1990, Rajan, 1992, von Thadden, 2004). In any case, the informed bank can always charge a risk premium to safe borrowers which is below the average risk premium. Therefore, the other banks suffer from a "winner curse" phenomenon, as some borrowers are likely to get attracted by these banks only because they are unprofitable. Therefore, when banks have unequal information on borrowers, the information asymmetry enables the most informed banks to charge interest rates above its marginal cost, and it softens competition.

Specific effects of competition under asymmetric information

The existence of information asymmetries helps to understand specific features of the banking competition, which depart from the perfect competition setting.

First, the ability of banks to extract more rent on their own borrowers over the course of their relationship gives rise to a specific price setting, sometimes mentioned as a "bargain then rip-off" price structure. As they expect to set high markup on future good borrowers, banks value and invest in relationships, such that they may compete more aggressively to attract new borrowers. Therefore, they effectively set bargain prices to first-time credit applicants, before charging higher markups as its information monopoly on these borrowers increases. Depending on the number of profitable borrowers and the strength of banks' information rent, this pattern may on average limit the price increase with respect to the situation where the information obtained by banks is non-exclusive.

The presence of asymmetric information also imply that a higher number of banks may lead to higher interest rates (Hauswald and Marquez, 2006). Indeed, the information rent of unprofitable borrowers benefits them mostly when many banks are present, as they can test more screening procedures and they face higher chances of being granted credit. Thus, the average quality of applicants decreases with the number of banks, and interest rates increase. Nevertheless, a higher number of banks may also decreases interest rates if it reduces banks' incentives to invest in monitoring technologies. Smaller expected market shares deprive banks from economies of scale in their monitoring technologies, and thereby they decrease future monopoly rents.

The "winner curse" phenomena also suggests that competing banks may face some incentives to share information on the declined applicants to reduce their screening costs (Pagano and Japelli, 1993) or to avoid financing unprofitable projects after screening costs get sunk (Dewatripont and Maskin, 1995).

Finally, the information advantage of incumbent banks generates barriers to entry for foreign banks (Dell'Ariccia, Friedman, and Marquez, 1999). Indeed, each incumbent bank can earn a profit from its information monopoly position over its own borrowers, even if outside applicants are unprofitable. Potential entrants only experience the downsides of the information asymmetry among banks, and they may be better-off not entering the market. As a consequence, information symmetry prevents the credit market from being contestable.[4]

[4]Many other barriers to entry are present in the banking industry, including regulatory compliance (capital and liquidity requirements, risk management), costly services tied to credit usage (branches, ATM), and IT costs.

Interactions with other sources of market failure in banking

The "information-based" theories of banking mentioned above are of central importance to justify the existence of banks in the first place, and they laid the ground to understand the main driving forces behind banking competition. However, this literature does not account for different market structures or industrial organization of banking firms (e.g, banks' relationships with their external suppliers, network externalities, change of business models). From this perspective, banks' market power may seem to be a natural by-product of banks, which is out of the reach of regulators.[5]

The industrial organization of banking ("IO", hereafter), to which this dissertation belongs, represents a strand of the literature which attempt to fill this gap, and therefore to complement the results from information theories. For this purpose, the IO focuses on partial equilibra, and it mostly considers situations where the market failure does not exist independently from banks. This enables this research field to consider more complex interaction among actors, and to derive more subtle guidelines to regulators when multiple market failures are present. As a consequence, the bank is defined as a single entity which set some optimal strategy in an environment which is constrained by the behavior of competitors, but also by other players such as customers or regulatory authorities. Its strategy may consist in setting interest rates, fees or choosing a form of organization.[6] Also, with respect to the IO literature in general, the IO literature on banking takes into account other sources of market failure common to many industries (including banking), from transaction costs to product differentiation, and it studies their interactions with bank-specific issues (information asymmetries, but also government intervention, network effects, or multi-product sales).

The literature in the IO of banking adopts different modeling choices to study the interaction between information on borrowers and other market failures, in order to study different questions. Based on their proximity to the "information-based" theories of banking and to standard IO, we may classify these models as follows:

1. *Differentiation as a source of information.* Closest to the "informational-based" literature, these models consider that banks are differentiated along some characteristic which represent their ability to obtain information on each borrower (e.g., Hauswald and Marquez, 2006). Most often, this characteristic represents the distance between the bank and each borrower, because distance erodes banks' ability to collect precise soft information

2. *Separate differentiation and information.* These models consider that differentiation,

[5] To some extent, this also reflects on the place often devoted to banking competition policy as a small section of stability regulation, where the uninformative consensus among academics and practitioners is that an intermediate level of competition is optimal.

[6] This set of strategies extends to strategies common to most industries (quantities, localization, entry), and to bank-specific decisions (e.g., liquidity choice or risk decisions).

or the market structure, is independent from banks' ability to extract rents from information. Therefore, they can study how asymmetric information interact with market structures (e.g., Dell'Ariccia, 2001).

3. *Differentiation as an exogenous measure of information rents.* Closest to the traditional IO literature, these models use some exogenous market characteristic to represent information rent. Most often, this characteristic is a lower marginal cost, or switching cost paid by locked-in borrowers to go to another bank (e.g., Gehrig and Stenbacka, 2007). This simple modeling of information rents enables these articles to study more complex strategies which are relevant in banking (price -discrimination based on borrowers' loyalty, obfuscation strategies).

In the first article of this dissertation, I contribute to this literature by studying the welfare effects of government intervention on the credit market, when borrowers face switching costs and banks can price-discriminate between borrowers based on the identity of their previous lender. In line with the models defined in 3), switching costs may be interpreted as a measure of banks' information rent over borrowers. Alternatively, they represent other transaction cost which must be supported by borrowers to begin a new relationship.

The second article of this dissertation estimates the effect of branch closures on borrowers' access to credit. In the spirit of the models in 1), it examines if borrowers are harmed when the distance to their branch increases, or if they already proved to be creditworthy when they were granted their previous loan(s).

Finally, the third article deals with a different topic, because it studies banks' incentives to outsource. However, it assumes that the primary function of each bank is to allow their depositors to exchange payments, and that borrowers can only exchange with borrowers from the same bank when payment systems are incompatible. Similar to the informational value derived during the relationship, attracting depositors generates an indirect benefit for banks, because other depositors will value the opportunity to exchange with an additional person.

2 Recent changes in information & competition in banking

Pre-crisis changes

Beginning in the 1970s, the banking sector experienced a process of deregulation[7] and breakthroughs in information technologies. As a consequence, banks consolidated (see

[7] In the United States, the prohibition of interest on demand deposit was lifted in 1980, to enable banks to compete for deposits with mutual funds on a context of strong inflation.

Vives, 2016) and shifted from traditional lending activities to market-based activities and financial services to investors and firms (consulting, insurance, investment funds, underwriting).

Banks began to provide credit using a large set of lending technologies (see Udell, 2015, for survey), which qualifies the equivalence between soft information and lending to SMEs and households. It became unclear to what extent banks remained specialized in information collection with respect to capital markets (Fama, 1985), or to other financial intermediaries (e.g., Carey, Post and Sharpe, 1996). Two innovations epitomize the increasing importance given to hard information in bank lending.

In the late 80's, credit scoring technology spread quickly in the US and in Europe. Based on multivariate statistical analysis, they became widely used to assess the credit worthiness of small individual and corporate borrowers. The diffusion of monitoring based on hard information limits the technological rent of banks, therefore increasing competition on the lending market. It also limits the ability of loan officers to lend too much and to accept risky borrowers (Heider and Inderst, 2012).

More than credit score, the development of securitization in the 1990s is a canonical example of a financial innovation which decrease the importance of relationship lending. Securitization enables banks to transform a pool of illiquid loans into tradable instruments which are sold to investors. Securitization ultimately still relies on banks screening borrowers and granting loans. However, banks could depart from their traditional functions of monitor and to enforcer of repayment collection (*originate-to-hold)*, and adopt a *originate-to-distribute* business model where the credit risk is transferred to outside investors.

The competitive effect of a more efficient information collection by banks depends on whether it reduces the value of relationship lending (Hauswald and Marquez, 2003). In this respect, securitization led to a higher competition on credit markets among banks with similar screening abilities. It may also foster the entry of uninformed banks on the credit market, because these banks will benefit from being the only banks to sell good loans on the security market (Frankel and Jin, 2015). However, data analysis tools may provide an additional value of banking relationships, when they analyze private data such as reimbursement frequency or when the information on existing borrowers helps the bank improving its proprietary credit scoring.

Post-crisis changes

Traditional issues of competition policy regained in importance following the financial crisis, and it generated new challenges for the regulation authorities.

Despite a progressive normalization of competition policy in banking since the 1970s[8], the banking sector has long been exempted from some competition requirements which applied to other industries. The reason is threefold. First, and as we saw in the previous section, the shift to market-based activities increased the contestability in banking from outside banks and other financial intermediaries alike. In addition, the suspicion that lower margins generates risk-taking incentives on banks, or that banks' rents serve as a cushion against shocks, has conditioned the reach of competition policy into banking to stability oversight. Third, theoretical arguments suggest that the competitive effects of a public intervention are at most a minor concern. Adapted from merger advocacy in manufacturing industries, a failing-firm defense for instance stresses that letting a bank fail would generate direct competitive costs and contaminate competitors, such that bailing-out banks improves competition and welfare.

The origination of the financial crisis, and the importance of the maturity mismatch, questions the validity of the first two arguments. Also, it became clear in the case of large banks that the alternative to bailout, if any, could not always be represented by an exit, depending on the importance of the bailed-out bank on a given market and the intensity of the shock. Whether or not they increase the aggregate level of competition, bailouts upset the level-playing field among competing banks by subsidizing targeted institutions. Their direct effect is to increase the margins and the market share of supported banks. They also decrease the margin of non-targeted banks, in a context where competition for scarce funding sources is intense (Gropp, 2011, Berger and Roman, 2015).

Competition authorities in Europe and in the UK stepped actively in state aid plans. They ordered divestitures in many circumstances (e.g., Commerzbank, WestLandesbank and Royal Bank of Scotland), and they supported other state aid plans including such balance-sheet reductions. Given the urgency of bailouts, they had to quickly strike a balance between preventing competitive distortions, and maintaining important actors on each market (see Beck et al, 2010, for a discussion of the DG Competition doctrine).[9] Also, these measures may also act as a form of punishment on misbehaving banks, such that they represent a convergent instrument for stability and competition purposes. More generally, this new role assumed by competition authorities participates to the regulatory shift from *containment* policy to *resolution* mechanisms (Honohan et Laeven, 2005), which aim to develop more long-sighted policies to cop with financial crises, and to avoid the recourse to bailout policies.

The implication of competition authorities in the clearing process of bailout policies highlights the need to maintain a ready to use, detailed level of knowledge of each financial market, and to be able to assess and compare the consequences of divestitures on impacted

[8] In the EU, the application of the Treaty of Rome into banking can be traced back to the *Züchner case* in 1981.

[9] In the case of state aid programs designed to the banking sector as a whole, banks' participation to the program represents an additional constraint on the determination of the compensations

parties precisely. Alternatively, the implementation of new resolution tools (e.g., bail-in, sale of business, bridge institution) may require similar trade-offs between the severity of the burden on banks and the protection of competition.

Innovation and new financial actors

Innovations in the analysis of hard information on borrowers lead to the entry of new financial actors on the lending market. Following the development of securitization, shadow banks grew because of their specialization in servicing, structuring, and funding loans on wholesale markets. Nevertheless, banks remained at the core of the financial industry. More recently, Fintech firms such as Peer-to-Peer (P2P) platforms take advantage of the latest advances in data analytics (machine learning, artificial intelligence) and the profusion of (non)-financial data to match potential lenders and investors. Similarly, BigTech firms use their own platform data to bypass the need to produce relationship-based information on borrowers.

Boot et al. (2021) highlight that these new firms are likely to exert a stronger pressure on banks' competitiveness than shadow banking because it erodes both the information rent and the communication channel advantage of banks. First, the combination of non-financial data with hard information on borrowers can significantly improve credit risk evaluation, such that banks' rent from its exclusive access to soft information may be eroded. Second, changes in consumption habits in general favor digital-native credit platforms, which can fit these new usages better and at a fraction of the cost of branch networks.

In line with these changes in consumption habits, one of the most important changes over the past decade within banks has been the rapid decline in the size of branch networks. This represents a challenge for banks' activities, for two reasons. First, it jeopardizes the soft information gathered by loan officers through long-term relationships with their borrowers. Branch closure are thus likely to decrease the information and spatial capture of banks on borrowers. Together with the loss of interest of consumers for local branches mentioned above, branch closures also suggest that banks loose part of their communication advantage over other intermediaries. Until recent years, branches represented the most straightforward point of contact to credit access for potential borrowers, and they were used as a showcase for banks to attract borrowers. Today, the rise of direct financing services from digital platforms is a more convenient point of access to credit for customers, because the credit offer is directly bundled with the purchase of a product, and it can be used as a wallet to buy millions of other items.

Data sharing with outsiders and cyber risks

The digitalization of the economy sets consumer data as a valuable commodity for firms. On the market for consumer data, the marketing of financial information represent a possible source of additional revenues for banks or consumers.[10] The effect of data monetization on banking competition is very likely to depend on the legislation regarding consumer ownership on their data and data standardization requirements. In this perspective, the UK *Open Banking Standard* in 2017 and the European *Payment Services Directive* in 2019 require banks to share data with other financial firms, conditionally on consumer agreement.[11] Therefore, the main objective of these legislations was not only to protect consumers' data from harmful use of personal data, but also to allow consumers to enjoy more data-intensive services from third parties, by voluntary disclose personal data with them.

It is a priori likely that these data sharing agreements benefit borrowers as long as they mitigate the information rent of incumbent banks without "over-empowering" third parties entrants. However, the voluntary nature of this disclosure separates these initiatives from good old industry-level information sharing agreements. This raises specific concerns. First, this may introduce unintended inequalities among borrowers. Borrowers who do not share their data for idiosyncratic reasons (privacy concerns, lack of sophistication, or without need for the new service) risk to be pooled with borrowers reluctant to share their bad information (He et al., 2020). Also, it may foster aggregate data disclosure by consumers, with ambiguous consequences on competition. In this respect, Lam and Lui (2020) show that data portability facilitates the entry of new competitors for a given of volume of data in the industry. However, data portability may reinforce incumbents if the prospect of easier switching induce consumers to be less sensitive to the volume of data they share with their incumbent banks.

The increasing valuation of consumers' financial data also led to an intensification of cyber threats for banks' IT systems. Due to its ability to transfer money and its importance as an infrastructure, the banking sector is naturally a main target for cyber attacks. However, cyber risk represent a challenge for the banking sector, because it differs in various aspects from the other risks routinely monitored by banks and supervisors, i.e., credit risk, operational risk, liquidity risk, equity market and interest rates risks. Indeed, cyber attacks result from a malicious intent, they can remain undetected and evolve quickly, and they occur with a higher probability than other risks (Kashyap, Wetherilt, 2019). As a consequence, cyber threats represent a new and impredictable risk for banking systems. These risks are all the more impredictable as banks increasingly outsource the management of their IT systems to third-party providers, with unclear implications on the overall level

[10] For examples of monetization of spending information by banks, see Withers I & White L. (2019) 'Dollars in the detail: banks pan for gold in 'data lakes', *Reuters*.

[11] Outside Europe, the only major legislative initiative to date is the Australian *Consumer Data Right Act*, passed in 2019.

of security of financial institutions.

In light of the risk that cyberattacks pose to financial stability, the regulation on banks began to evolve quickly. Until the introduction of the *Digital Operational Resilience Act* (DORA) in Europe, cyber risk regulation remained widely under-developed for most banks, as it fell at the intersection of data privacy legislation and of guidelines on operational risk management.[12] Specifically, DORA introduces similar cyber-security requirements to critical third parties as to financial institutions.

Similar to the cyber risk regulation, the nascent literature on the competitive effects of cyber risk draws from the literature on privacy protection, and it studies how cyber risk and privacy protection interact. The risk of data leakage limit firms' incentives to sale consumers' information to third-parties because it would reveal its privacy intrusion and undermine firms' main source of profit (Jullien et al., 2020). However, the imperfect sensitivity of consumers to cyber risk fosters over-sharing of data with respect to first-best (Lam and Seifert, 2021). Overall, firms' infringement on privacy decreases with cyber risk, but the intensity of this effect depends on the awarness of consumers to privacy and cyber risks.

Despite its importance for financial stability, the specific consequences of cyber risk for banks remain largely unexplored. The sensitivity of banks' information on borrowers and depositors suggest that cyber risks would cause a major reputation damage and potential liquidity crisis for the attacked banks (Duffie and Young, 2019). Also, competition among banks imped information and technological sharing with other banks (see Atkins and Lawson, 2021, on the US Financial Services Sector), and it may foster under-disclosure of cyber incidents to the public. Finally, cyber attacks may alter the integrity of data on borrowers, with unclear consequences on competition among banks.

3 Plan of the dissertation

This dissertation presents three chapters which assess the effects of some of the recent changes in the banking industry on the welfare of banks' consumers. Each chapter studies a different change in the banking industry, and its interaction with specific risks faced by consumers.

1. The first chapter investigates changes in bailout policies, when banks may face liquidity constraints or fail.
2. The second chapter studies branch closures, which may compromise banks' relationship to their borrowers.

[12]The IT systems of systemic banks are subject to additional scrutiny from national defense departments, when they are considered to be a critical infrastructure.

3. The third chapter focuses on bank outsourcing its payment system, when banks and depositors face cyber risk.

All three chapters aim to offer different perspectives on the same research question: what are the consequences of some change in the banking industry on consumers' welfare? We will answer this question using a theoretical model when studying liquidity shocks and cyber incidents (chapters 1 and 3), while we estimate the effect of branch closures empirically (chapter 2).

A central question of all of our two theoretical analysis will be to understand how the change in the banking industry (in the bailout policy or in outsourcing) affects banks' prices and risk strategies. Also, we will provide extensive welfare analysis, and discuss the efficiency of some policy instruments aimed at protecting consumers.

An important common question of chapters 1 and 2 is to study whether borrowers can be better-off following a disruption in their banking relationships. Also, we discuss in both cases how the effects of a change in banks' market structure are heterogeneous across borrowers, with a focus on borrower sophistication and on their proximity to other lenders.

In the following paragraphs, we provide an overview of the three chapters of this dissertation.

Article 1 - Bailout policies when banks compete with switching costs

In this chapter, co-authored with Marianne Verdier, we argue that retail borrowers may not benefit from bailout policies because of switching costs and price discrimination among borrowers. We study how government intervention impacts lending market competition with switching costs given that the government hedges banks (either totally or partially) against the risk of experiencing funding constraints or failures.

Our main results are as follows. First, we show that the government protection strengthens competition before a shock if it increases enough the probability of market stability. Indeed, switching costs provide banks with incentives to invest in market share, in order to extract rents from their myopic borrowers in the future. Bailout policies insure banks against the risk to be unable to convert their initial market share advantage into profit, thereby reinforcing competition to attract borrowers. However, a bailout policy may also reduce banks' probabilities to monopolize the market in the future, such that it may also reduce banks' incentives to invest in market share before a shock. This countervailing effect may sometimes compensate for the market stability effect and increase initial interest rates, but otherwise, lenient bailout policies increase competition before a shock.

We then show that the results obtained with myopic borrowers may no longer hold when borrowers are forward-looking. A bailout that preserves the stability of the market structure benefits more myopic borrowers, while a bailout policy restricted to one bank benefits more borrowers if they are forward-looking. Indeed, forward-looking borrower prefer to belong to a bank with a initial small market share, as the other bank will need to set very low interest rates to attract borrowers from this bank in the future. Therefore, forward-looking borrowers have a low sensitivity to initial interest rates when they expect the market to remain stable. This effect disappears when they expect only one bank to stay on the market, such that they are more sensitive to initial interest rates in this case.

Third, we show that the surplus effects of bailout policies are heterogeneous across borrowers. A bailout that preserves banks' lending capacities increases the surplus of consumers who can only regain access to credit because of the intervention. Moreover, consumers benefit from a larger set of switching options. However, the bailout policy enables banks to price-discriminate among borrowers, such that they may set higher interest rates if switching costs are high. From a social welfare perspective, the option to switch given by the bailout may be socially wasteful if too many borrowers use it. Whether a bailout increases social welfare ex post depends on banks' financial constraints, on the profitability of the project and the level of switching costs. Therefore, the government faces a trade-off between preserving banks' lending capacities and limiting inefficient poaching.

In the spirit of an influential policy recommendation (Vickers, 2010), we finally analyze how setting lower switching costs change the marginal impact of government intervention on the expected social welfare. We show that the combination of lower bailout expectations and lower switching costs may not increase the expected social welfare. The outcome depends on whether banks are exposed to a common shock and whether the government relaxes banks' funding constraints fully when it intervenes.

Article 2 - Branch closures and access to credit: do severed relationships harm borrowers?

In this chapter, I study the effect of branch closures on the intensive credit margin of corporate borrowers in France, and I explore potential mecanisms driving this effect.

The recent acceleration in branch closures in Europe and in the United States has probably been the most visible transformation in the banking industry in the past decade, and it has drawn much attention in the political debate as well as in the media. However, evidences on their effect on credit access remain scarce, especially under favorable economic conditions and outside bank mergers.

We use information on branch closures and on their localization from the directory of branches issued by the *Banque de France*, that we match with credit information at the firm-branch level from the French credit registry. We focus on the period between January 2015 and March 2020, which represent a period of relative credit expansion for corporate borrowers and stability for the French banking sector.

To control for the potential endogeneity of branch closures with respect to borrowers' characteristics, we require an exact matching on firms' characteristics, bank, and credit relationship variables, one quarter before the branch closes. Also, we take into account the staggered nature of branch closures in our period by following the estimation procedure of Cengiz et al. (2019). Therefore, we form matched-cohort datasets for every treated borrower, and we estimate the effect of the branch closure using a difference-in-differences within each matched cohort.

The results are as follows. We observe that borrowers from closed branches experience a lower decrease in their amount of credit than similar borrowers. After two years, they hold 6% more credit because of the closure. This effect is robust to variations within our matched sample and to additional fixed effects and control variables, and it is homogeneous with respect to borrowers' size and to the number of their banking relationships. As an exception, the loan amount of riskier borrowers remains unchanged following branch closure. Borrowers drawn steady amounts of credit, but they increase the volume of their overall available credit. Therefore, this relative increase in credit does not represent a lifting of stronger credit constraints before the closure, and it targets most favored borrowers.

We then investigate if this relative increase in credit amount occurs because the bank which decided the closure increases its credit supply, or if competing branches contribute to this effect as well, in which case branch closures affects borrowers' demand. The supply-side interpretation may relate to efficiency gains due to branch consolidation, while the demand-side interpretation suggests that the branch closure represents for borrowers an opportunity to renegotiate their credit, or to search for a new branch. We first provide two evidences which favors the demand-side interpretation. Borrowers whose branch closed because of a bank merger do not experience an increase in credit. Also, using the estimation method of Khwaja and Mian (2008) and focusing on borrowers with multiple relationships, we show that receiving branches do not increase their total supply of credit with respect to the borrowers' other banks.

Finally, in line with our previous interpretation, we highlight that the only borrowers who benefit from an increase in credit amount are located in areas with dense branch networks. This result is robust to focusing on borrowers in rural areas, or including branches from neighbor towns. This role of local competition suggests that borrowers seize the opportunity of their branch closures to renegotiate existing credit conditions with their bank, or to engage in new credit relationships.

Article 3 - Cyber Security and Cloud Outsourcing of Payments

In this chapter, co-authored with Marianne Verdier, we study banks' incentives to outsource their retail payment system to a cloud service provider when cyber risk exists.

We consider a model where banks compete in the downstream market of deposits and offer payment services to their consumers, which quality depends on the security of their payment systems. Some depositors are naive, while other are sophisticated and choose their banks according to the level of risk of its payment system. Since banks are unable to price discriminate between consumers, the price of deposits reflects banks' horizontal differentiation on the Hotelling line and banks' vertical differentiation in terms of payment system security.

A cloud service provider in our model offers two different services to banks: a storage capacity and a payment app. There is a fee for each service. If banks use the storage service, they transfer a share of their security of payment system to the cloud service provider which can hide the realization of cyber incidents to banks to avoid being liable. If, in addition, the banks' depositors are equipped with the same payment app, they are compatible, i.e., they can send payments to one another.

We first show that outsourcing payment systems to a common cloud service provider may improve welfare, because it avoids a duplication of security costs among banks. In general, the outsourcing decision benefits the society if and only if the marginal benefits of interoperability are sufficiently high with respect to the potential marginal costs in terms of security.

In line with the existing literature, we show that, without cyber risk, banks are biased towards excessive outsourcing because compatibility enables banks to soften competition on the deposit market. However, we show that the presence of cyber risk may offset banks' incentives to outsource excessively and may even imply that banks sometimes do not outsource enough their payment systems with respect to the social optimum. This result is caused by several distortions with respect to the first-best. The vertical structure of the market adds several layers of inefficiencies caused by the timing of the investment and pricing decisions, the presence of moral hazard, and the presence of naive depositors. Some effects reinforce the bias towards excessive outsourcing caused by network externalities, while other may compensate for it, and even reverse it, such that banks may sometimes under-outsource their payment services.

The vertical market structure implies the following distortions. First, the cloud service provider chooses its prices after banks choose their investments in security. This implies that it does not internalize the impact of its pricing strategy on banks' investment incentives. Because of this timing, the cloud service provider may under-estimate banks' rents of outsourcing, and offer its services too rarely compared to the first-best. This effect weakens the bias towards excessive outsourcing. Second, banks' investment incentives are distorted by the presence of moral hazard. However, in our paper, the effect of moral hazard on banks' investment in cyber security is ambiguous. On the one hand, banks have incentives to over-invest to protect themselves from the additional damage caused by under-reporting of cyber incidents. On the other hand, banks also benefit from the under-reporting of cyber incidents, as this enables them to avoid becoming liable towards their depositors. Thus, the moral hazard effect may either reinforce or weaken the bias towards excessive outsourcing caused by network externalities. Third, the cloud service provider does not internalize the impact of banks' expected damage on competition for depositors. In addition, neither the banks nor the cloud service provider internalize the expected losses incurred by the naive depositors.

We conclude the paper by discussing how the liability regime for cyber incidents, the ability of a judge to separate the responsibilities of each firm before cyber incidents occur, and a public infrastructure for payment systems impact payment system security and banks' outsourcing decisions.

Bibliography

[1] Beck, T., Coyle, D., Dewatripont, M., Freixas, X. & Seabright, P. (2010): "Bailing out the banks: reconciling stability and competition," *Centre for Economic Policy Research*, 18.

[2] Berger, A.N. & Roman, R.A. (2015): "Did TARP banks get competitive advantages?" *Journal of Financial and Quantitative Analysis*, 50(6), 1199–1236.

[3] Boot, A., Hoffmann, P., Laeven, L. & Ratnovski, L. (2021): "Fintech: what's old, what's new?" *Journal of Financial Stability*, 53, 100836.

[4] Broecker, T. (1990): "Credit-worthiness tests and interbank competition," *Econometrica*, 429–452.

[5] Carey, M., Post, M. & Sharpe, S.A. (1998): "Does corporate lending by banks and finance companies differ? Evidence on specialization in private debt contracting," *The Journal of Finance*, 53(3), 845–878.

[6] Cengiz, D., Dube, A., Lindner, A. & Zipperer, B. (2019): "The effect of minimum wages on low-wage jobs," *The Quarterly Journal of Economics*, 134(3), 1405–1454.

[7] Dell'Ariccia, G., Friedman, E. & Marquez, R. (1999): "Adverse selection as a barrier to entry in the banking industry," *The RAND Journal of Economics*, 515–534.

[8] Dell'Ariccia, G. (2001): "Asymmetric information and the structure of the banking industry," *European Economic Review*, 45(10), 1957–1980.

[9] Dewatripont, M. & Maskin, E. (1995): "Credit and efficiency in centralized and decentralized economies," *The Review of Economic Studies*, 62(4), 541–555.

[10] Diamond, D.W. (1984): "Financial intermediation and delegated monitoring," *The Review of Economic Studies*, 51(3), 393–414.

[11] Duffie, D., & Joshua Y. (2019): "Cyber runs," *Brookings.*

[12] Fama, E.F. (1985): "What's different about banks?" *Journal of Monetary Economics*, 15(1), 29–39.

[13] Frankel, D.M. & Jin, Y. (2015): "Securitization and lending competition," *The Review of Economic Studies*, 82(4), 1383–1408.

[14] Gehrig, T. & Stenbacka, R. (2007): "Information sharing and lending market competition with switching costs and poaching," *European Economic Review*, 51(1), 77–99.

[15] Gropp, R., Hakenes, H. & Schnabel, I. (2011): "Competition, risk-shifting, and public bail-out policies," *The Review of Financial Studies*, 24(6), 2084–2120.

[16] Hauswald, R. & Marquez, R. (2003): "Information technology and financial services competition," *The Review of Financial Studies*, 16(3), 921-948.

[17] Hauswald, R. & Marquez, R. (2006): "Competition and strategic information acquisition in credit markets," *The Review of Financial Studies*, 19(3), 967–1000.

[18] He, Z., Huang, J. & Zhou, J. (2020): "Open banking: credit market competition when borrowers own the data," *National Bureau of Economic Research*, w28118.

[19] Heider, F. & Inderst, R. (2012): "Loan prospecting," *The Review of Financial Studies*, 25(8), 2381–2415.

[20] Holmstrom, B. & Tirole, J. (1997): "Financial intermediation, loanable funds, and the real sector," *The Quarterly Journal of Economics*, 112(3), .663–691.

[21] Honohan, P. & Laeven, L. eds., (2005): "Systemic financial crises: Containment and resolution," *Cambridge University Press.*

[22] Jullien, B., Lefouili, Y. & Riordan, M.H. (2020): "Privacy protection, security, and consumer retention," *SSRN Working Paper.*

[23] Kashyap, A.K. & Wetherilt, A. (2019): "Some principles for regulating cyber risk," *AEA Papers and Proceedings,* 109, 482–87.

[24] Khwaja, A.I. & Mian, A. (2008): "Tracing the impact of bank liquidity shocks: Evidence from an emerging market," *American Economic Review*, 98(4), 1413–42.

[25] Lam, W.M.W. & Liu, X. (2020): "Does data portability facilitate entry?" *International Journal of Industrial Organization*, 69, 102564.

[26] Lam, W.M.W. & Seifert, J. (2021): "Regulating Data Privacy and Cybersecurity", *Journal of Industrial Economics.*

[27] Leland, H.E. & Pyle, D.H. (1977): "Informational asymmetries, financial structure, and financial intermediation," *The Journal of Finance*, 32(2), 371–387.

[28] Milgrom, P.R. & Weber, R.J. (1982): "A theory of auctions and competitive bidding," *Econometrica*, 1089–1122.

[29] Pagano, M. & Jappelli, T. (1993): "Information sharing in credit markets," *The Journal of Finance*, 48(5), 1693–1718.

[30] Rajan, R.G. (1992): "Insiders and outsiders: The choice between informed and arm's-length debt," *The Journal of Finance*, 47(4), 1367–1400.

[31] Sharpe, S.A. (1990): "Asymmetric information, bank lending, and implicit contracts: A stylized model of customer relationships," *The Journal of Finance*, 45(4), 1069–1087.

[32] Udell, G.F. (2015): "SME Access to intermediated credit: What do we know and what don't we know," *Small Business Conditions and Finance Conference,* 61–109.

[33] Vives, X. (2016): "Competition and stability in banking," *Princeton University Press*.

[34] Von Thadden, E.L. (2004): "Asymmetric information, bank lending and implicit contracts: the winner's curse," *Finance Research Letters*, 1(1), 11–23.

Bailout Policies when Banks Compete with Switching Costs

Bailout Policies when Banks Compete with Switching Costs

N. Ciet & M. Verdier

Abstract

We analyze the welfare effects of bailout policies when banks compete with switching costs. We show that higher bailout expectations of banks reduce the interest rates paid by borrowers ex ante (i.e., before a shock), as long as they do not reduce too much banks' probabilities to monopolize the market. This pro-competitive externality of government intervention hinges on the inability of borrowers, as opposed to banks, to foresee the consequences of the intervention. If borrowers are sophisticated too, another design of intervention may be preferable. Ex post, a bailout increases the interest rates paid by borrowers as well as social welfare if borrowers cannot easily switch banks and if the financing capacity of banks is strongly impaired by the shock. Finally, the overall effect of government intervention on expected welfare depends on the correlation of risks among banks and on the magnitude of the support offered by the government.

Keywords: Bailout, Bank Failure, Switching Costs, Lending Market.
JEL Codes: L1, L5, G2.

1 Introduction

Does market structure stability benefits borrowers by reducing interest rates? The lending market is an example of a market in which government intervention may hedge firms (banks) against the risk of experiencing funding constraints that could increase output prices. During financial crisis, governments often decide to bail out banks after liquidity shocks. Such interventions contribute to restoring banks' lending capacities by relaxing their funding constraints.

Whether financial stability benefits retail borrowers by reducing credit prices and improving access to credit is still an opened research question.[1] On the one hand, financial stability benefits borrowers by preserving competition in the retail credit market (see Calderon and Schaeck, 2016, Vives, 2016). This first concern is justified by the risk that bank failures may increase credit prices, financial constraints and switching costs of retail borrowers (e.g., see the Vickers report, 2010, in the U.K.). On the other hand, bailout policies may increase banks' incentives to take risks and *moral hazard*. This second argument explains why several regulators have designed new policy instruments to avoid bank bailouts since the 2008 crisis (e.g., in Europe, in the U.S.).[2]

In this paper, we argue that retail borrowers may not benefit from market structure stability because of *switching costs*, which build an essential aspect of competition in credit markets (see Shy, 2002, Kim et al., 2003, Degryse and Ongena, 2008). We study how government intervention impacts lending market competition with switching costs given that the government hedges banks (either totally or partially) against the risk of experiencing funding constraints or failures. In our setting, banks compete for two periods to offer credit to borrowers who incur switching costs and may poach the consumers of their rival in the second period of competition.

We obtain the following results. If switching costs are high, borrowers who would not have lost access to credit after a shock do not benefit ex post from government hedging, since they pay higher interest rates if there is a bailout. However, if banks expect a higher probability of a bailout, they may lower their interest rates in the first period of competition. Banks make this decision if they anticipate that government intervention increases more the probability that the market structure remains stable than it reduces their probabilities to monopolize the market. Otherwise, higher bailout expectations may increase first period interest rates. We also analyze how the ability of borrowers to form expectations about market structure stability impacts our results. Finally, we derive the conditions such that policies designed to reduce switching costs increase the social value of lowering banks' bailout expectations. We show that the combination of lower bailout expectations and lower switching costs may not increase the expected social welfare. The outcome depends on whether banks are exposed to a common shock and whether the

[1] The concept of financial stability is much broader than the notion of market structure stability that we use in our paper. A financial system is stable if it is resilient to shocks that impact asset prices and the allocation of funds in the economy. This definition includes general equilibrium effects of shocks on the financial system. We define the notion of market structure stability as the fact that the number (and the identity) of competitors remains constant across periods, with the same technologies and production capacities.

[2] The introduction of new safety-net tools, from higher capital requirements to appropriate resolution policies, is expected to constitute a "farewell to bailout" (Benczur et al., 2017). For example, the Dodd-Frank Act in the United States has introduced strict limits on the government ability to conduct bailouts (see the title XI of the Dodd-Frank Act). In Europe, the Banking Recovery and Resolution Directive limits public recapitalization to solvent institutions. Moreover, it requires sufficient burden-sharing, restructuring plans and minimum competitive distortions.

government relaxes banks' funding constraints fully when it intervenes.

Our findings echoe a report by the UK Independent Commission on Banking, which concluded that the presence of switching costs in retail banking markets is central to financial regulation (see p.17 of the Vickers Report, 2010). Unlike other initiatives in OECD countries, the Vickers report articulates the competition policy with the regulatory agenda.[3] It concludes by presenting a large set of regulatory instruments to decrease switching costs, such as the regulation of account closure, account transfer fees, data portability, and the prohibition of early repayments. In our paper, we derive the conditions such that these instruments can also be used to make a no-bailout policy welfare-enhancing. We find that lower bailout expectations may not maximize the expected social welfare in a low switching costs environment.

We construct a framework to study how switching costs impact the social value of bank bailouts in retail credit markets. Banks compete à la Hotelling for two periods to offer credit to retail borrowers. The latter incur switching costs in the second period if they do not remain with their initial bank. A fraction of borrowers is forward-looking and forms expectations regarding the future competitive conditions in the credit market. In the second period, banks price discriminate between their first period borrowers (i.e., their insiders) and the borrowers of their competitor (i.e., their outsiders). Between the two periods, a liquidity shock may change the competitive conditions in the credit market. Without governement intervention, if the shock is severe, banks may either fail or ration credit. The market structure is then either a monopoly, or a duopoly, possibly with restricted lending capacities. If the governement intervenes, it may save both banks, or only one bank. Moreover, it may restore banks' lending capacities either totally or partially.

Banks choose their interest rates in the first and the second period according to their expectations regarding the bailout policy. Without government intervention, if the shock is severe, banks expect to operate with funding constraints after the shock, under either monopoly or duopoly. They may also exit the market. With full support from the government, banks expect the preservation of the duopolistic market structure and their lending capacities.

We show that bailout policies increase second period interest rates for both insider and outsider borrowers if switching costs and banks' funding sources are high enough with respect to the profitability of the credit market. When banks compete with switching costs, they have incentives to offer attractive poaching rates to the borrowers of their competitor, while extracting rents from their installed base of consumers. Bailout policies preserve the duopolistic market structure and consumers' outside option to switch to another bank. However, the value of this outside option decreases with the level of switching costs and

[3] Following the Vickers report, the program "Banking for the 21st Century" implemented both information disclosure between banks and an online service to facilitate and guarantee switching. For a survey of policies in OECD countries dealing with switching costs in banking, see OECD (2009).

increases with the value of the project that needs to be financed. As a consequence, borrowers may face higher interest rates following a bailout if switching costs are high and if the profitability of the credit market is low.

We proceed by analyzing the impact of a bailout on the first period interest rates paid by borrowers if the latter are myopic. We show that higher bailout expectations decrease the interest rates paid by borrowers if a bailout preserves market stability. This result is caused by banks' ability to price discriminate in the second period between their insider and outsider borrowers. Because of switching costs, banks have incentives to invest in market share in the first period to extract rents from their consumers in the second period. Bailout policies insure banks against the risk to be unable to convert their first period market share advantage into profit, thereby reinforcing competition to attract borrowers.

The mechanism that drives this result is as follows. Without government intervention, a bank may either fail or face funding constraints. In principle, banks' incentives to discount their first period interest rates are higher if they expect to become a monopoly than if they expect to compete under duopoly. This difference is caused by the strategic complementarity between insider and outsider interest rates under duopoly, which softens competition for borrowers in the first period. However, as (symmetric) banks expect to become a monopoly with probability one half if this situation occurs, the effective discount rate offered to borrowers in the first period is in the end lower under monopoly than under duopoly. Hence, a bailout preserving market stability (i.e., a duopoly) reinforces competition for borrowers in the first period and reduces first period interest rates. However, a bailout policy may also reduce banks' probabilities to monopolize the market in the second period, such that it may also reduce banks' incentives to invest in market share in the first period. This countervailing effect may sometimes compensate for the market stability effect and increase first period interest rates.

We then analyze how the results obtained with myopic borrowers evolve if some borrowers are forward-looking. We are able to show that a bailout that preserves the stability of the market structure benefits more borrowers if the latter are myopic than if they are forward-looking. On the contrary, a bailout policy restricted to one bank benefits more borrowers if they are forward-looking than if they are myopic.

Finally, we analyze the effects of bailout policies on consumer surplus and social welfare. A bailout that preserves banks' lending capacities increases the surplus of consumers who regain access to credit. Moreover, consumers benefit from a larger set of switching options. However, the latter may pay higher interest rates if there is a bailout because of switching costs and poaching strategies. For this reason, the option to switch may be more socially wasteful if too many borrowers use it. Whether a bailout increases social welfare ex post depends on banks' financial constraints, on the profitability of the project and the level of switching costs. We show that the government faces a trade-off between restoring banks' lending capacities and limiting inefficient poaching. The effect of government intervention on the expected social welfare depends on how much it increases banks' expectations of market stability, and whether market stability enhances welfare when it prevents competition with financial constraints to arise. Then we analyze how switching costs change the marginal impact of government intervention on the expected social welfare. We show that several cases may arise (increasing, decreasing or U-shaped relationship) depending on the correlation of banks' risk of failure and the magnitude of the support offered by the government when it intervenes.

The remainder of the paper is as follows. In Section 2, we position our paper in the literature on switching costs and bank bailouts. In Section 3, we introduce our model. In Section 4, we determine the interest rates chosen by banks when the market structure is uncertain in the second period. In Section 5, we analyze the effect of bailout policies on bank prices and social welfare. In Section 6, we extend our baseline model by endogenizing banks' investment in liquidity management and by allowing the surviving bank to engage in a P&A transaction. Finally, we conclude.

2 Related literature

Our article contributes to the research on banking regulation by bridging a gap between two different strands of literature, that is, a family of papers dealing with switching costs in retail banking and another group of papers analyzing the impact of bank bailouts on competition.

To our knowledge, the paper by Stenbacka and Takalo (2019) is the only work analyzing the relationship between switching costs and financial stability. Unlike in our paper, their objective is to understand how switching costs in the market for deposits may destabilize banking markets. They model two banks facing exogenous stochastic investment opportunities, which may fail if the return on their portfolio is not sufficient to reimburse depositors. They show that, with inherited customer relationships, lower switching costs increase the probability of bank failure.

In our paper, we address a different issue, because we focus on the lending market. Our objective is to understand how market structure stability and bailout policies may impact the interest rates paid by retail borrowers when the latter incur switching costs. This explains why we choose to model poaching (history-based pricing), which is more relevant for the lending market than for the deposit market.[4] This assumption can also be motivated by the works of Ioannidou and Ongena (2010) or Barone, Felici and Pagnini (2011), who show the existence of price discrimination between old and new borrowers in the market for corporate loans in the presence of switching costs. Unlike in the market for deposits, borrower switching behavior is not a source of financial instability in banking

[4]Stenbacka and Takalo (2019) do not use poaching in their model of the deposit market for the same reason.

markets. Borrowers rather face the consequences of bank failures when banks do not meet their credit needs or when they are forced to switch banks after a liquidity shock. Therefore, our work is focused on the consequences of market structure instability for retail borrowers rather than on the sources of financial instability. Moreover, we consider a specific source of market structure instability that is due to the scarcity of banks' funding sources after a liquidity shock.[5]

Bailout policies and bank competition Bailout policies impact competition between banks through different channels. First, bailout policies preserve market stability. On the one hand, a higher number of competitors decreases interest rates margins and lending rates (see Vives, 2016, Bouckaert and Kort, 2014, Calderon and Schaeck, 2016, for the empirical analysis).[6] However, Bertsch, Calcagno and Le Quement (2015) note that market stability makes tacit coordination more easily sustainable. Our paper complements this literature by analyzing whether market stability benefits borrowers when banks compete with switching costs. We show that borrowers who are already related to a solvent bank may not benefit ex post from the preservation of a competing bank because of switching costs and poaching strategies. Bailout policies benefit borrowers only if switching costs are low enough after the liquidity shock.

Second, bailout policies distort competition because too-big-to-fail banks benefit from lower funding costs through implicit public guarantees.[7] This phenomenon has two opposite effects on credit prices. On the one hand, unlike smaller banks, too-big-to-fail banks enjoy greater market power. On the other hand, they may also pass through lower funding costs into lower credit prices. In our paper, we model ex ante symmetric banks which incur the same funding cost. However, in our setting, banks may be ex post asymmetric because the state may decide to support only one bank. We show that both banks may enjoy lower market power in the first period because of competition with switching costs even if government intervention increases the probability that one bank monopolizes the market (qualified as too-big-to-fail ex post).

Several papers focus on the impact of bailout policies on banks' investment behavior and moral hazard (Dell'Ariccia and Ratnovski, 2013, Acharya and Yorulmazer, 2007).

[5]A further issue for research consists in analyzing how borrower switching costs impact borrowers' incentives to default strategically. Such a mechanism could impact banks' probabilities of failure.

[6]In the banking industry, the relationship between an increase in the number of competitors and lower interest rates is not straightforward (Degryse et al., 2009). Furthermore, this relationship may depend on the business cycle. There is indeed empirical evidence that bank loan markups tend to move countercyclically (Mandelman et al., 2011; Aliaga-Díaz and Olivero, 2010). Those movements arise even independently of the variations in borrowers' riskiness during the business cycle because of the presence of switching costs.

[7]Based on these concerns, state aid has sometimes been made conditional on activity restrictions. For instance, restrictions and divestments were imposed, respectively, on the retail deposit and credit activities of Northern Rock and RBS following public support (Beck et al., 2010).

This literature underlines that risky activities are sensitive to a trade-off between higher revenues and the preservation of banks' charter value (Keeley, 1990, Perotti and Suarez, 2002). In our model, we focus on how exogenous liquidity shocks may impact the surplus of borrowers given banks' bailout expectations. Therefore, we do not model moral hazard on the asset side of banks' balance sheet. In the extension section, we analyze how switching costs impact banks' incentives to manage their liquidity risk cautiously.

Market displine by investors may exacerbate the competitive distortions induced by a bailout. In our setting, we analyze the role of banks' bailout expectations and do not study the impact of investors' expectations on market structure stability. Focusing on the effect of lower refinancing costs on risk-taking, Hakenes and Schnabel (2010) show that a bailout unambiguously leads to higher risks for a protected bank if investors can observe its level of risk. In either case, non-protected banks react by taking on more risks if they expect a higher probability of bailout for their competitor (Gropp et al., (2011)).

Our work is also related to a large empirical literature studying how changes in market structure (failures, branch closures, mergers) and market conditions may impact the supply of credit (see Schwert (2018), Berger, Makaew and Roman (2019), and Degryse, Masschelein and Mitchell, (2011)). In our paper, we do not model banks' decisions to ration their credit supply and rather focus on the impact of the risk of experiencing funding constraints on banks' intertemporal pricing strategy. The literature on the bank lending channel shows that liquidity shocks impact consumer access to credit according to the strength of the lending relationship (e.g., Petersen and Rajan, 1995). Yanelle (1997) studies how competition for lending capacities in the deposit market impacts loan prices in the second period of competition. By contrast, we consider that banks face uncertain exogenous lending capacities and model competition in the lending market for two periods.

The empirical literature concludes that bank bailouts have effects on both the extensive and the intensive margins of banks.[8] In our framework, we analyze how banks' bailout expectations impact their interest rates and borrowers' incentives to switch banks after a liquidity shock.

Switching costs and retail banking We build on the standard setting of competition with switching costs developed by Klemperer (1995) and apply it the banking industry. In this framework, firms choose to keep prices down in the short run if this enables them to extract higher rents from consumers in the second period.[9] As Fudenberg and Tirole (2000), Gehrig and Stenbacka (2007) and Ahn and Breton (2014), we allow banks to poach

[8]The literature finds mixed results on the impact on bank bailouts on the extension of credit supply (see the book by Berger and Roman, 2020, for a survey). Berger, Makaew and Roman (2019) provide empirical evidence on the impact of bank bailouts on banks' intensive margins.

[9]Our results are also related to the literature revisiting the effect of switching costs on average prices when markets feature product differentiation (See Dubé et al. (2009), Shin and Sudhir (2009), Cabral (2016)).

the consumers of their competitor.[10] We contribute to this literature by analyzing whether government intervention after liquidity shocks improve borrower surplus when the latter incur switching costs. There is strong evidence that switching costs play an important role in shaping competition in the banking industry (Shy, 2002, Kim et al., 2003, and Degryse and Ongena, 2008 for a survey of the empirical literature) but also that consumers incur specific costs of switching after a branch exit (Bonfim et al., 2020). Poaching strategies are empirically confirmed by several studies (Bouckaert and Degryse (2004), Hauswald and Marquez (2006) and Ioannidou and Ongena (2010), Carbo-Valverde et al. (2011), Barone et al. (2011)).

Financial structure stability and product market competition Finally, our work is also connected to a literature in industrial organization that studies how firms' financial structure impacts product market competition (Chevalier and Scharfstein, 1996). By contrast, we assume that banks' financial structure is exogenous and that the market structure is uncertain. This enables us to analyze how banks and borrowers' expectations impact the interest rates. However, this means that other aspects of bank bailouts are not addressed in our paper.[11] In particular, we do not study the optimal resolution of banks (see Skeel (2014), Walther and White (2020), Bolton and Oehmke, (2019)). We only discuss in the extension section a resolution method in which the remaining bank engages in a Purchase and Assumption transaction to acquire the borrowers of the failing bank.

3 The model

We build a model to analyze how the design of the bailout policy impacts the interest rates charged by banks before and after the bailout according to the level of switching costs and the severity of the banks' funding constraints. The framework of competition with switching costs that we consider is similar to Klemperer (1995), except that we add consumer poaching and uncertainty on banks' lending capacities in the second period.

There are three dates in the economy ($\tau = 0, 1, 2$) and two types of risk-neutral agents: two banks and a continuum of borrowers. We refer to the period between $\tau = 0$ and $\tau = 1$ (resp., between $\tau = 1$ and $\tau = 2$) as the first period (resp., the second period). Borrowers need short-term bank credit at each period to undertake a project. However, banks are exposed to a liquidity shock just before $\tau = 1$, which may constrain their lending capacities in the second period. Depending on the market structure after the liquidity shock, borrowers may either borrow from the same bank, switch banks, or may not have

[10] Gehrig and Stenbacka (2007) and Ahn and Breton (2014) model poaching in the banking sector to study the effects of information disclosure and securitization, respectively.

[11] Given that banks' financial structure is exogenous, banks do not adapt their lending capacities to their bailout expectations.

access to bank credit. The role of the bailout consists in hedging banks (and borrowers) against liquidity shocks that may impact banks' lending capacities in the second period.

Credit market competition Two banks, A and B, compete à la Hotelling to offer credit to retail consumers in a two-period game.[12] The marginal cost of lending is $c > 0$ for the two periods and is independent of the bailout policy.[13] The profit of bank $k \in \{A, B\}$ in the credit market in period $l \in \{1, 2\}$ is π_k^l. Both banks are exogenously located at the two extremes of a linear city of length one, with bank A being at point 0 and bank B at point 1. Banks set different interest rates for their borrowers in each period. In the first period, bank k sets the interest rate r_k^1 that maximizes the expected discounted value of its profit over the two periods. The common discount factor of banks is denoted by δ^{FI} and we assume that $\delta^{FI} < 1$ (FI standing for financial intermediaries). In the second period, banks are able to "poach" the customers of their rival by attracting them with a lower interest rate. The interest rate charged by bank k to its borrowers (the "insiders") is r_k^i, whereas the interest rate charged to the borrowers of its competitor (the "outsiders") is r_k^o.[14]

Borrowers On the Hotelling line, there is a continuum of borrowers, whose preferences are uniformly distributed on $[0, 1]$ and are invariant over time.[15] In each period, a borrower needs one dollar of bank credit to invest in a homogeneous project that returns ρ with probability p and 0 with probability $1 - p$. The expected (net) return of the project is $R = p\rho - c > 0$. At the end of each period, the loan is reimbursed if the investment is successful and the borrower defaults otherwise. The borrower is protected by limited liability and the return of the project is perfectly observable.[16]

In each period, a borrower chooses among borrowing from bank A, borrowing from

[12]One limitation of the two-period setting is that it introduces distortions with respect to an infinite period model because a firm has little to lose from increasing its price in the second period.

[13]The marginal cost of lending includes banks' funding cost. We discuss in the extension section how our results are modified if banks' funding cost in the first period depends on the bailout policy.

[14]In a supplementary material that is available upon authors' request, we show that a price-discrimination strategy is a Nash equilibrium of the game in which banks make the choice to price discriminate in the second period.

[15]One interpretation of this assumption is that the differentiation in the services provided by each bank remains unchanged between the two periods. In the literature on competition with switching costs, Beggs and Klemperer (1992) make the same assumption, whereas in Von Weisacker (1984) and Cabral and Villas-Boas (2005) the consumer location in the second period is independent from the first period.

[16]The borrowers' risk is constant across periods. Therefore, the effects that we highlight in our model are not caused by variations in the borrowers' riskiness during recession periods. In our setting, we do not endogenize the entrepreneur's choice of the level of risk of the project. Boyd and De Nicolo (2005) show that higher lending rates may increase entrepreneurs' incentives to take risks, thereby increasing banks' vulnerability to credit risk. However, modelling this type of risk is not the focus of our model.

bank B, and not borrowing, which yields a reservation utility of zero.[17] Borrowers have a transportation cost of $t > 0$ per unit of length. The transportation cost can be interpreted as either the degree of differentiation between the two banks or the cost of reaching a bank branch. The information on the expected return of the project is known by banks at no cost.

In the second period, borrowers can remain with the same bank, decide not to borrow or switch to the competing bank and incur a switching cost $s > 0$. A proportion $\eta \in [0, 1]$ of borrowers is myopic, i.e., they choose their bank in the first period without considering the effect of their choice on the utility that they obtain in the second period.[18] Therefore, myopic borrowers neither anticipate switching costs nor the possible evolution of the market structure. The rest of the borrowers (in proportion $1-\eta$) are forward-looking and anticipate the possible evolution of the market structure in the second period when they choose their home bank in the first period. The borrowers' discount factor is given by δ^b. Forward-looking borrowers have the same expectations as banks regarding the market structure that emerges in the second period.

Second period competition: market structure and funding constraints At the beginning of each period, each bank raises short-term debt, which maximum amount is normalized to 1 (e.g., deposits, commercial paper, wholesale funding). The debt is raised from a dedicated pool of investors and matures at the end of each period.

Just before the end of the first period (i.e., $\tau = 1$), banks may be hit by a liquidity shock that may prevent them from reimbursing their investors.[19] After the liquidity shock, banks may be either financially constrained in the second period of competition or fail. We assume that if a bank is constrained, the efficient credit-rationing rule applies. Therefore, the bank first serves the consumers who have the highest willingness-to-pay for credit, that is, the closest consumers on the Hotelling line. Banks' lending capacities on the Hotelling line after the liquidity shock are given by the measure $\lambda_h \in [0, 1]$ and depend on the market structure indexed by h. Bank A may serve the consumers located between point 0 and point λ_h, whereas bank B may serve the consumers located between $1 - \lambda_h$ and point 1. We distinguish four possible market structures $h \in \{ms, fc, m, e\}$ in the second period:

[17] Hence, we assume that borrowers do not hold multiple credit relationships in a given period. Empirical evidence on multirelationship lending suggests both large variations between countries and firm sizes (Neuberger and Räthke, 2009). In our model, we allow for a different relationship at a refinancing stage, so that the two credit lines do not partly overlap only to simplify exposure. Furthermore, we focus on long-term credit, which is more likely to be singular than liquidity services (Ongena and Smith, 2000).

[18] We assume that neither banks nor borrowers can over-borrow in the first period to compensate for the probability of facing credit constraints in the second period. Hence, we do not take into account the effects of an intertemporal allocation of the borrowers' wealth on prices (Jeanne and Korinek, 2019).

[19] We give in the online Appendix H an example of a liquidity shock that fits into our model. In our baseline model, liquidity problems arise simply because of bad luck rather than because of excessive risk taking by the bank's management. We discuss in our extension section this assumption.

- **Market stability** $(h = ms)$**:**

The market is stable after the liquidity shock if both banks remain active without funding constraints (i.e., $\lambda_{ms} = 1$). This situation may either result from the small magnitude of the liquidity shock or from the government intervention to bailout banks.

- **Competition with funding constraints** $(h = fc)$**:**

If both banks survive with financial constraints, we assume that their lending capacity under duopoly is symmetric and given by $\lambda_{fc} < 1$. This situation may either result from the higher magnitude of the liquidity shock or from the government's bailout policy.

- **Monopolization by one bank** $(h = m)$**:**

If only one bank survives, it ends up as a monopoly with a restricted lending capacity given by $\lambda_m < 1$.[20] This situation may either result from the higher magnitude of the liquidity shock or from the government's decision to support only one bank.

- **Market exit of both banks** $(h = e)$**:**

This case arises if both banks exit the market after the liquidity shock and if the government does not intervene (i.e., $\lambda_e = 0$).

The bailout mechanism If banks face liquidity problems, the government can prevent them from failing or facing financial constraints by using taxpayer money.[21] We assume that there are neither administrative nor funding costs associated to the bailout. Moreover, to simplify our setting, we consider that banks' cost of funding is not altered by a bailout.[22]

We describe banks' expectations regarding the government's bailout policy by the likelihood of a bailout (i.e., the parameter $\beta \in [0, 1]$) and the magnitude of the support offered to banks by the government if there is an intervention (i.e., the parameter $\alpha \in [0, 1]$). As regards the likelihood of government intervention, there is often some constructive ambiguity ex ante regarding the government's bailout intentions, because the government cannot credibly commit that it will not bailout banks.[23] If $\beta = 0$, banks never expect the

[20] Therefore, we assume away the case where the financial capacity of a surviving bank remains unaltered when the competitor fails. If only one bank remains active in the market, banks' lending capacities are asymmetric and the lending capacity of the other bank is null. However, to economize on the parameters of the model, we do not add different indexes for each bank in that case.

[21] For a discussion of state-supported schemes for financial institutions, see Beck et al. (2010).

[22] For instance, in exchange for its guarantee, the government charges a fee per dollar of insured liability which corresponds to the market return demanded by investors before the shock. This fee can be interpreted as a direct funding cost, an opportunity cost of funds or a measure of the guarantee premium. Alternatively, a recapitalization or a toxic assets relief enables the banks' risk premium to decrease to its pre-shock value.

[23] From an empirical perspective, banks' bailout expectations may depend on political factors and market conditions (see Dam and Koetter, 2011).

government to intervene, whereas if $\beta = 1$ banks expect the government to intervene if needed.

The magnitude of the support offered by the government determines banks' financial constraints. The parameter α represents the probability, conditional on the decision to intervene, that the government offers its full support to both banks and preserves *market stability*. In that case, banks operate without funding constraints after the bailout. With probability $1-\alpha$ the government only offers a limited support to banks, which no longer preserves market stability. In practice, governments may decide to implement targeted bailout policies through partial recapitalizations or toxic-asset reliefs programs.[24] Two cases may arise. Either the government may decide to support both banks but restricts their lending capacities. In that case, there is *competition with financial constraints* in the second period. Or the government may support only one bank (with equal probability) and there is *monopolization* of the market.

To economize on the parameters of the model, we make additional assumptions when the government offers partial support to the banking sector. First, if both banks are about to exit the market, the government bails out at most one bank. Moreover, we assume that if only one bank remains active after the liquidity shock, the government offers partial support to both banks. All the mechanisms of the model are independent of these assumptions.

Banks' expected market structure in the first period We assume that in the first period, banks form symmetric expectations regarding the competitive conditions that prevail after the shock. Given the probability that the government intervenes $\beta \in [0,1]$ and the probability $\alpha \in [0,1]$ that the government offers its full support to banks after its intervention, banks expect the market structure $h \in \{ms,\ fc,\ m,\ e\}$ to arise with probability $\widetilde{p}_h(\beta,\alpha) \in [0,1]$. The probabilities $\widetilde{p}_h(\beta,\alpha)$ are detailed in the Appendix 0. If $\beta = 0$, the government never intervenes after the liquidity shock and the market structure h arises with probability $\widetilde{p}_h(0,\alpha) = p_h$.[25] In the baseline model, the probabilities p_h for $h \in \{ms,\ fc,\ m,\ e\}$ are exogenous. We then discuss an extension of our framework in which higher bailout expectations reduce the probability p_{ms} that the market structure remains stable. [26]

Assumptions: We make the following assumptions on the parameters of the model:

(A1) $t \geq s$.

[24]Monetary policy and government guarantees on banks liabilities are most often designed to preserve funding liquidity. However, the intensity of their support may also vary with the security requirements demanded on banks' assets, or contingent on the respect of regulatory guidelines.

[25]As there are four possible market structures $h \in \{ms,\ fc,\ m,\ e\}$ after the liquidity shock in our setting, we have $p_{ms} + p_{fc} + p_m + p_e = 1$.

[26]Dam and Koetter (2011) measure empirically how banks' expectations impact their incentives to take risks (distinguishing bad luck from bad behavior).

Assumption (A1) ensures that both banks poach some of their competitor's borrowers in the second period in the equilibrium of the game.

(A2) $\lambda_{fc} \in (0, 1/2)$.

Assumption (A2) ensures that if banks are constrained by their lending capacity, there is an equilibrium in pure strategies to the subgame in which banks choose their prices in the second period.

(A3) $\lambda_m \in (1/2, \overline{\lambda}_m)$ with $\overline{\lambda}_m \equiv \min\{1/4 + (R - s)/2t, 1\}$.

Assumption (A3) implies if a bank operates as a monopoly in the second period, it has sufficient funds to lend to some (but not all) borrowers of the failed bank.[27]

Assumptions (A2) and (A3) imply that if one bank fails, its competitor benefits from a higher lending capacity than if both banks remain active with financial constraints, that is, we have $\lambda_{fc} \leq \lambda_m$. This may be due to a transfer of funds from the investors of the failing bank. However, we do not make the assumption that the total lending capacity of the banking sector is higher under monopoly than under duopoly (i.e., we may have either $\lambda_m \geq 2\lambda_{fc}$ or the reverse).

Finally, we make two additional assumptions to ensure that the market is covered in both periods when banks compete without funding contraints:

(A4) $\delta^{FI} p_{ms} \geq 1/2 + 3\delta^b(1 - \eta)/(3 + \delta^b \eta)$ and

(A5) $R > \underline{R} \equiv \max\{3t/2 - s/3, t + s/2\}$.

Timing of the game: The timing of the game is as follows:

- At $\tau = 0$, each bank k sets an interest rate r_k^1. Borrowers choose which bank to borrow from and whether to borrow. They invest in their project, the outcome of the investment is realized, and they repay their loans if the project is successful.
- At $\tau = 1$, the liquidity shock may be realized. It may impact the market structure either by triggering the failure of one or two banks, and/or by reducing banks' lending capacities. Following the liquidity shock, the government may bail out the banking sector and preserve (or not) banks' lending capacities.
- At $\tau = 2$, banks observe the bailout decision and the resulting market structure. Each active bank k chooses the interest rates r_k^i for its insiders and r_k^o for its outsiders. Borrowers choose which bank to borrow from and whether to borrow. They invest in their project, the outcome of the investment is realized, and they repay their loans if the project is successful.

[27] There is empirical evidence that borrowers are less credit constrained in markets where banks enjoy greater market power (see Bergstresser, 2008), which could also be a motivation for our assumption.

4 Competition between banks under uncertainty

In this section, we analyze how banks choose their interest rates given their expectations of the market structure after the liquidity shock.

In the second period, given its first period market share, each bank k chooses the interest rate that maximizes its second period profit and makes a profit π_k^2. In the first period, each bank k chooses the first period interest rate that maximizes the expected discounted value of its profit given by $\pi_k = \pi_k^1 + \delta E(\pi_k^2)$, where the profit of bank k in the first period is given by

$$\pi_k^1 = x_D(pr_k^1 - c), \tag{1.1}$$

the indifferent borrower between bank A and bank B in the first period is given by

$$x_D = \frac{t + p(r_B^1 - r_A^1)}{2t}. \tag{1.2}$$

and $E(\pi_k^2)$ refers to the expected profit of bank k in the second period.

Banks' expected profit in the second period $E(\pi_k^2)$ depends on their expectations regarding the evolution of the market structure $h \in \{ms, fc, m, e\}$ and is given by

$$E(\pi_k^2) = \widetilde{p}_{ms}(\pi_k^2)^{ms} + \widetilde{p}_{fc}(\pi_k^2)^{fc} + \frac{\widetilde{p}_m}{2}(\pi_k^2)^m.^{28} \tag{1.3}$$

As this framework of competition with switching costs is standard in the literature (see Klemperer, 1995), we only detail the results in a symmetric equilibrium that will be useful for the analysis of the impact of the bailout on borrower surplus. The only difference with respect to the literature is the uncertainty of the market structure in the second period. Hence, banks' trade-off between first period and second period profits depends both on banks' and borrowers' expectations regarding the evolution of the market structure. For further details, the reader can refer to Appendix B.

To ensure the existence of a symmetric equilibrium, we make the following assumption:

(A6) $s > t(1 - \lambda_{fc})$.

Assumption (A6) ensures that banks have incentives to reduce their interest rates in the first period, even if they expect to operate as a constrained (local) monopoly at $t = 2$ (see the online Appendix I). Such a condition is satisfied if the marginal gains from attracting an insider borrower exceed the marginal losses of forgoing an outsider borrower in the first period when all borrowers are myopic.[29]

[29] If Assumption (A6) does not hold, it is profitable for one bank to increase its first period interest rate to lose some market share, because the marginal benefit from price discrimination between insiders and outsiders is higher than the gain from serving only insiders.

Proposition 1 gives the profit-maximizing interest rates in the second period of competition in a symmetric equilibrium.

Proposition 1. In the second period, banks charge interest rates that depend on the stability of the market structure and their funding constraints.
- If the market is stable, both banks remain active and do not face funding constraints. Each bank k charges an interest rate $(r_k^i)^{ms} = (c + 2t + s)/3p$ to its insiders and $(r_k^o)^{ms} = (3c + t - s)/3p$ to its outsiders.
- If banks compete with financial constraints, they serve only their insiders and charge them the interest rate $(r_A^i)^{fc} = \rho - t\lambda_{fc}/p$.
- In the monopolization case, only bank k remains active and charges the interest rates $(r_k^i)^m = \rho - t/2p$ to its insiders and the interest rate $(r_k^o)^m = \rho - (t\lambda_m + s)/p$ to its outsiders.

Proof. Appendix A. ■

In the second period, banks are able to price discriminate between their insiders and their outsiders. The interest rate charged to their insiders increases with the level of switching costs, reflecting banks' market power on their insiders. By contrast, banks lower the interest rate charged to their outsiders to compensate for switching costs.

Proposition 2 gives the interest rates charged by banks in the first period of competition in a symmetric equilibrium.

Proposition 2. In the first period, if all borrowers are myopic, each bank $k \in \{A, B\}$ charges an interest rate

$$r_k^1 = \frac{c+t}{p} - \overline{\sigma},$$

where $\overline{\sigma} = \delta^{FI}(\widetilde{p}_{ms}\sigma_{ms} + \widetilde{p}_m\sigma_m/2)/p > 0$ represents the discount offered to borrowers compared to the optimum under static competition. The discount offered to borrowers depends on banks' expectations of the market structure and we have $\sigma_{ms} = 2s/3$ and $\sigma_m = s - t(1 - \lambda_m)$.

Proof. Appendix B. ■

If all borrowers are myopic (i.e., $\eta = 1$), banks reduce their interest rate compared to the optimum under static competition (i.e., $(c + t)/p$) by offering a discount given by $\overline{\sigma}$ to their borrowers.[30] This strategy enables them to enjoy higher rents from competition in the second period. This result is standard in the literature on competition with switching costs. Banks invest in market share in the first period and harvest the profits of their investment in the second period. The discount $\overline{\sigma}$ is decreasing with the level of switching costs.

As there are four possible market structures in the second period ($h \in \{ms,\ fc,\ m,\ e\}$), the discount $\overline{\sigma}$ should be the sum of four terms, each of them reflecting the expected

[30] From Assumption (A6), we have $s > t(1 - \lambda_m)$, which implies that $\sigma_m > 0$.

benefits of investing in market share in the first period given that market structure h emerges in the second period. However, banks will not be able to harvest the benefits of their first period investment in market share if they compete with funding constraints ($h = fc$) or if they exit the market ($h = e$). Hence, $\overline{\sigma}$ is the only the sum of two terms that reflect banks' benefits of investing in market share if the market remains stable ($h = ms$) or if they monopolize the market ($h = m$).

Proposition 3 gives the first period interest rates if some borrowers are forward-looking.

Proposition 3. If some borrowers are forward-looking, each bank $k \in \{A, B\}$ charges an interest rate given by

$$r_k^1 = \frac{c+t}{p} - \overline{\sigma} + \Delta(\eta, \sigma_f, t/p),$$

where

$$\Delta(\eta, \sigma_f, t/p) = \frac{t(1-\eta)\sigma_f}{p(1+\eta\sigma_f)}$$

represents the adjustement of the interest rate that is due to borrowers' expectations of the market structure, and σ_f is given by $\sigma_f = \delta^b(2\widetilde{p}_{ms} - 3\widetilde{p}_m)/6$. The function Δ is increasing with σ_f, t/p and decreasing with η.

Proof. See Appendix B. ■

If borrowers are forward-looking, the latter take into account the interest rates paid after a shock in their choice of their home bank in the first period. The borrowers' sensitivity to first period interest rates depends on their expectations of the second period market structure. Note that the level of switching costs has no impact on the adjustement of first period interest rates that is due to the borrowers' expectations. This is because the borrowers' expected switching costs are independent of their choice of bank in a symmetric equilibrium.[31]

If the indifferent borrower believes that the market will certainly remain stable ($h = ms$), he has incentives to seek credit from the bank with the smallest market share first in order to benefit from lower poaching interest rates later. This effect implies that he is less sensitive to first period interest rates. Hence, banks increase their interest rates compared to the case in which all borrowers are myopic. Note that if banks and forward-looking borrowers believe that the market structure will remain stable ($\widetilde{p}_{ms} = 1$), we have $\sigma_f = \delta^b/3 > 0$.[32]

[31]When borrowers expect market stability, this result holds because we assume third-degree discrimination to be feasible (see Klemperer, 1987).

[32]If forward-looking borrowers are uncertain about their future preferences, they also have lower sensitivity to initial prices in models without second period price discrimination (Cabral and Villas-Boas, 2005), unless they expect future prices to be constant (Von Weizsäcker, 1984).

By contrast, if the indifferent borrower believes that only one bank will remain active ($h = m$), he favors the bank with the biggest first period market share. If his home bank remains active, the latter will set a lower second period interest rate to keep serving him. If his home bank fails and he is forced to switch, the remaining bank charges him an interest rate that only depends on its financial constraint (independently of first period interest rates). Hence, borrower demand is, on average, more sensitive to first period interest rates than in an environment in which all borrowers are myopic. This effect exacerbates competition among banks in the first period. Thus banks may set lower interest rates than if all borrowers are myopic. Note that if banks and forward-looking borrowers expect one bank to monopolize the market ($\widetilde{p}_m = 1$), we have $\sigma_f = -\delta^b/2 < 0$.

5 The impact of a bailout policy

In this section, we use the results of our baseline framework to analyze the impact of a bailout policy on the interest rates charged by banks, on consumer surplus, and social welfare.[33]

5.1 The impact of bailout expectations on first period interest rates

Banks' bailout expectations impact the probability $\widetilde{p}_h$ that the market structure $h \in \{ms, fc, m, e\}$ emerges in the second period. Given banks' evaluation of the probability β that the government intervenes and the probability α that the government offers its full support to the banking sector, the probabilities $\widetilde{p}_h(\beta, \alpha)$ are given by

$$\widetilde{p}_h(\beta, \alpha) = p_h + \beta\phi_h(\alpha),$$

where $\phi_h(\alpha) = \widetilde{p}_h(1, \alpha) - \widetilde{p}_h(0, \alpha)$ represents the marginal impact of a higher probability of government intervention on banks' expectations. From Proposition 2 and 3, banks take only into account their expectations of market stability $\widetilde{p}_{ms}$ and monopolization $\widetilde{p}_m$ in their choice of their first period interest rates. From (1.7a) (of Appendix 0), government intervention increases marginally banks' expectations of market stability by $\phi_{ms}(\alpha) = (1 - p_{ms})\alpha > 0$. From (1.9a), government intervention may either increase or decrease banks' expectations of monopolization by $\phi_m(\alpha) = (1 - \alpha)p_e - p_m$.

Myopic borrowers In Proposition 4, we analyze whether a higher probability of government intervention provides banks with incentives to reduce their first period interest rates when all borrowers are myopic.

[33]The analysis of the effect of bailout policies on banks' profits are available upon request.

Proposition 4. If all borrowers are myopic, a higher probability of government intervention β reduces the first period interest rates paid by borrowers if either: i) $\phi_m(\alpha) \geq 0$, ii) $\phi_m(\alpha) < 0$ and $\phi_{ms}(\alpha) \geq -3\phi_m(\alpha)/4$, or iii) $\phi_m(\alpha) < 0$, $\phi_{ms}(\alpha) < -3\phi_m(\alpha)/4$ and $s < s_1$, where

$$s_1 \equiv \frac{3t(1-\lambda_m)\phi_m}{4\phi_{ms} + 3\phi_m}.$$

Proof. From Proposition 2, we have $\partial r_k^1/\partial\beta < 0$ if and only if $\partial\overline{\sigma}/\partial\beta > 0$. Since $\partial\overline{\sigma}/\partial\beta = \delta^{FI}(\phi_{ms}\sigma_{ms} + \phi_m\sigma_m/2)/p$, if condition i) of Proposition 4 holds we have $\partial\overline{\sigma}/\partial\beta > 0$. Replacing for $\sigma_{ms} = 2s/3$ and $\sigma_m = s - t(1-\lambda_m)$ gives

$$\partial\overline{\sigma}/\partial\beta = \delta^{FI}((4\phi_{ms} + 3\phi_m)s - 3t(1-\lambda_m)\phi_m)/(6p).$$

If condition ii) of Proposition 4 holds, as $\phi_m < 0$ and $4\phi_{ms}+3\phi_m > 0$, we have $\partial\overline{\sigma}/\partial\beta > 0$. If condition iii) of Proposition 4 holds, we have $\partial\overline{\sigma}/\partial\beta > 0$ if and only if $s < s_1$. Note that as $\phi_m < 0$ and $4\phi_{ms} + 3\phi_m < 0$, we have $s_1 > 0$. ■

The result of Proposition 4 provides insight into the complex relationship between market structure stability and the interest rates paid by retail borrowers when banks compete with switching costs. A higher probability of government intervention may benefit retail borrowers ex ante if it increases much more banks' expectations of market stability than it reduces banks' expectations of monopolization. In case banks expect a strong reduction of their probabilities to monopolize the market, higher bailout expectations may increase first period interest rates if switching costs are high.[34]

The intuition of the result is as follows. Banks' bailout expectations impact their incentives to invest in market share in the first period. As shown in Proposition 2, if all borrowers are myopic, banks offer a discount to their borrowers in the first period that depends on their estimated probabilities that the market structure remains stable or that a bank ends up as a monopoly.

A higher probability of government intervention increases marginally banks' expectations of market stability (by $\phi_{ms}(\alpha) > 0$). The higher the probability that the market structure remains stable, the higher the banks' incentives to decrease their first period interest rates. Indeed, if banks expect to be fully supported by the government, they face higher chances of harvesting the benefits of their investment in market share than in any other market structure that could emerge without government intervention. If banks compete with funding constraints or exit the market, they cannot harvest the benefits of their first period investment in market share. The probability to harvest the benefits of their investment is also lower if banks expect a monopoly, because each bank has a

[34] These two effects are very general and do not depend on the specific values of banks' probabilities that we consider in our setting.

probability one half to exit the market.[35] Hence, the higher $\phi_{ms}(\alpha)$, the higher banks' incentives to reduce their first period interest rates.

A higher probability of governement intervention may either increase or decrease marginally banks' expectations to monopolize the market (by $\phi_m(\alpha)$, which sign may be positive or negative). If banks expect to monopolize the market, they have also incentives to discount their first period interest rate because of switching costs. Their incentives to discount their first period interest rates are higher than if they expect to exit the market. However, if a higher probability of government intervention reduces banks' probabilities to monopolize the market, it provides banks with lower incentives to increase their first period interest rates.

If $\phi_m(\alpha) > 0$ (Proposition 4 (i)) or if $\phi_m(\alpha) < 0$ and $\phi_{ms}(\alpha) \geq -3\phi_m(\alpha)/4$ (Proposition 4 (ii)), the monopolization effect is either positive, or outweighted by the market stability effect. Thus, a higher probability of government intervention reduces first period interest rates. Since the discount $\overline{\sigma}/p$ offered to consumers increases with switching costs, banks' incentives to reduce their first period interest rates are all the more important since switching costs are high.

If $\phi_{ms}(\alpha) < -3\phi_m(\alpha)/4$, the monopolization effect is negative, while the market stability effect is low. In this situation, banks expect to government to provide a limited support, and they may face lower incentives to invest in market shares. The monopolization effect outweights the market stability effect for high levels of switching costs. Thus, a higher probability of government intervention may increase first period interest rates when switching costs are high. When switching costs decrease, the marginal discount offered by banks when the government intervenes more (given by $\sigma_{ms}\phi_{ms} + \sigma_m\phi_m/2$) tends to increase. When switching costs are below the threshold value s_1, the market stability effect becomes dominant again and banks reduce their first period interest rates.

Finally, it is worth mentioning that the correlation of banks' risks of failure (through the probabilities p_e and p_m) and the probability α of a full support to both banks impact the outcome of government intervention.

An example: To illustrate the mechanism of Proposition 4, it is useful to consider the specific case in which government intervention is certain ($\beta = 1$) and the government never offers its full support to the banking sector ($\alpha = 0$). The market stability effect is equal to zero and the monopolization effect is equal to $p_e - p_m$. If $p_e > p_m$, the monopolization effect

[35] In principle, banks' incentives to discount their first period interest rates are higher if they expect to become a monopoly than if they expect to compete under duopoly. This difference is caused by the strategic complementarity between insider and outsider interest rates under duopoly, which softens competition for borrowers in the first period. However, as banks expect to become a monopoly with probability one half if this situation occurs, the effective discount rate offered to borrowers in the first period is in the end lower in expectation of a monopoly than of a duopoly.

is positive. Banks expect that a systemic failure of both banks is much more likely than monopolization. A bailout policy supports one bank and provides banks with incentives to reduce their first period interest rates to invest in market share. If $p_e < p_m$, the monopolization effect is negative. Banks expect a high probability to monopolize the market without government intervention. In that case, banks have incentives to increase their interest rates in the first period of competition for high values of switching costs when their bailout expectations increase.

Forward-looking borrowers In Proposition 5, we now examine how the results of Proposition 4 change if some borrowers are forward-looking.

Proposition 5. If some borrowers are forward-looking, a higher probability of government intervention β reduces first period interest rates paid by borrowers if either: i) $\phi_m(\alpha) > 0$ and $\phi_m(\alpha) \geq 2\phi_{ms}(\alpha)/3$, ii) $\phi_m(\alpha) \leq \min\{2\phi_{ms}(\alpha)/3, -4\phi_{ms}(\alpha)/3\}$, $\phi_{ms}(\alpha) \geq 3\phi_m(\alpha)$ and $s > s_1 + s_2$, where

$$s_2 \equiv \frac{\delta^b}{\delta^{FI}} \frac{(2\phi_{ms} - 3\phi_m)t(1-\eta)}{|3\phi_m + 4\phi_{ms}|\,(1+\eta\sigma_f)^2},$$

or iii) $\phi_m(\alpha) < -4\phi_{ms}(\alpha)/3$ and $s < s_1 - s_2$.

Proof. From Proposition 2, we have $\partial\sigma_f/\partial\beta = \delta^b(2\phi_{ms}(\alpha) - 3\phi_m(\alpha))/6$. Since

$$\frac{\partial\Delta}{\partial\sigma_f} = \frac{t(1-\eta)}{p(1+\eta\sigma_f)^2},$$

we have

$$\frac{\partial\Delta}{\partial\beta} = \delta^b \frac{(2\phi_{ms} - 3\phi_m)t(1-\eta)}{6p(1+\eta\sigma_f)^2}.$$

We have $\partial r_k^1/\partial\beta < 0$ if and only if $-\partial\overline{\sigma}/\partial\beta + \partial\Delta/\partial\beta < 0$. If condition i) of Proposition 5 holds, we have $-\partial\overline{\sigma}/\partial\beta < 0$ and $\partial\Delta/\partial\beta < 0$. This implies that $\partial r_k^1/\partial\beta < 0$. If condition ii) of Proposition 5 holds, since

$$\partial\overline{\sigma}/\partial\beta = (2/3p)\delta^{FI}(\phi_{ms} + 3\phi_m/4)(s - s_1),$$

if $3\phi_m + 4\phi_{ms} > 0$, we have $\partial r_k^1/\partial\beta < 0$ if and only if

$$s - s_1 > \frac{\delta^b}{\delta^{FI}} \frac{(2\phi_{ms} - 3\phi_m)t(1-\eta)}{(4\phi_{ms} + 3\phi_m)(1+\eta\sigma_f)^2} \equiv s_2.$$

If $3\phi_m + 4\phi_{ms} < 0$, we have $\partial r_k^1/\partial\beta < 0$ if and only if $s < s_1 - s_2$. ■

Proposition 5 explains how the presence of forward-looking borrowers impacts banks' inventives to reduce their first-period interest rates when there is a higher probability of government intervention.[36] As shown in Proposition 5, the presence of forward-looking borrowers impacts banks' incentives to discount their first period period interest rates differently according to their expectations of the future market structure.

The effect of borrowers' expectations on government intervention ultimately depends on the design of the bailout. Suppose that $\phi_m = 0$ and $\phi_{ms} > 0$ such that there is a high probability that government intervention preserves market stability (i.e., case ii of Proposition 5). Banks reduce their first period interest rates for a smaller set of switching costs than if all borrowers are myopic ($s_2 = \delta^b t(1-\eta)/(2\delta^{FI}(1+\eta\sigma_f)^2) > 0$ and $s > s_1+s_2$). Hence, a full support to the banking sector benefits more borrowers if the latter are myopic than if the latter are forward-looking in the first period. By contrast, if $\phi_{ms} = 0$ and $\phi_m > 0$ (case iii of Proposition 5), banks reduce their first period interest rates for a larger set of switching costs than if borrowers are myopic ($s_2 = -\delta^b t(1-\eta)/(2\delta^{FI}(1+\eta\sigma_f)^2) < 0$ and $s < s_1 - s_2$). Thus, a bailout policy restricted to one bank benefits more borrowers if they are forward-looking rather than myopic.

Our results imply that, if the government favors market stability, it should not give too much information on its bailout intentions to borrowers. Unlike the existing literature which focuses on market transparency and investors' expectations (e.g., Hakenes and Schnabel, (2010)), we highlight that a better transparency of bailout policies may not benefit forward-looking borrowers.

5.2 The impact of a bailout on second period interest rates

We analyze whether the second period interest rates increase following a bailout compared to a reference situation with no government intervention.

Assessing the impact of the bailout ex post is worthwhile either if only one bank fails or if both banks are financially constrained if there is no intervention.[37] Depending on the intensity of the shock and the role of government intervention, we can distinguish two scenarios.[38]

- *Resilient banking sector*:

The banking sector is said to be resilient if both banks survive with financial constraints

[36] In a related work, Dimopoulos and Schürnhoff (2021) examine how borrower myopia impacts the costs of bailouts. In their model, a bailout may either weaken or strengthen borrowers' incentives to strategically default. Unlike in their paper, we take into account consumer switching behavior and competition between banks.

[37] If both banks fail, firms do not borrow in the second period. If both banks compete without financial constraints in the second period if there is no government intervention, the bailout has no impact on the second period interest rates.

[38] Note that we make a simplification by abstracting from studying a third scenario in which government intervention changes the market structure from a monopoly to a constrained duopoly. This case could easily be deduced from the other two cases that we consider.

if there is no government intervention. The role of the bailout policy in this case is to relax banks' financial constraints. The bailout changes the market structure from competition with funding constraints to market stability (i.e., $h = fc$ to $h = ms$).

- *Vulnerable banking sector*:

The banking sector is said to be vulnerable if only one bank survives if there is no government intervention.[39] The role of the bailout policy in this case is both to save the failing bank and to relax banks' financial constraints by offering its full support to both banks. The bailout changes the market structure from monopolization to market stability (i.e., $h = m$ to $h = ms$).

In Proposition 6, we establish that, in both scenarios, the effect of the bailout on interest rates depends on the level of switching costs and on banks' financial constraints. Indeed, both factors impact banks' ability to exert their market power in the second period. Naturally, as banks are able to price discriminate between their insider and outsider consumers, the result differs for these two categories of borrowers.

For this purpose, we define a threshold on the switching costs given by $s_r \equiv 3R - 7t/2$. Moreover, we introduce different thresholds on funding constraints for insiders and outsiders, given by $\lambda_i \equiv (R - s)/3t - 2/3$ and $\lambda_o = \lambda_i + (t - s)/(3t)$, respectively.

Proposition 6. If the banking sector is resilient, the bailout increases the interest rate charged to insider borrowers if $s > s_r$ and $\lambda_{fc} > \lambda_i$ and decreases it otherwise.
If the banking sector is vulnerable, the bailout increases the interest rate charged to insider borrowers if $s > s_r$ and decreases it otherwise.
If the banking sector is vulnerable, the bailout increases the interest rate charged to outsider borrowers if $s > s_r$ and $\lambda_m > \lambda_o$ and decreases it otherwise.

Proof. Appendix C. ■

In both scenarios, the bailout prevents the emergence of (local) monopolies by preserving competition among banks. However, it may increase the interest rates charged to borrowers in the second period if switching costs are high. Indeed, a bank increases the second period interest rates following a bailout if the proportion of stable funding sources and the level of switching costs are high relative to the net profitability of the credit market. If there is no bailout, following a severe liquidity shock, both insider and outsider borrowers cannot switch banks. The bailout generates instead alternative outside options for both types of borrowers, whose values are decreasing with switching costs and increasing with the profitability of the credit market.

For insider borrowers, the bailout gives them the outside option to switch under both scenarios. The value of this option is decreasing with switching costs, such that the insider interest rate is increasing with switching costs following a bailout. Hence, if switching

[39] We have assumed that if only one bank survives, it is financially constrained.

costs are high and if the profitability of the credit market is low, a bailout policy increases the interest rates charged to insider borrowers. For outsider borrowers, the bailout gives them the outside option to stay with the same bank if the banking sector is vulnerable. The value of this option is also decreasing with switching costs. Thus, the poaching rate becomes less sensitive to switching costs following a bailout. The interest rate charged to outsiders may be higher following a bailout if switching costs are high.

For outsiders (resp. insiders), these demand effects are reinforced (resp. mitigated) by the strategic complementarity between the interest rates charged to insiders and to outsiders under duopoly. Indeed, as switching costs increase, it becomes relatively less costly to attract outsiders and more costly to keep insiders under duopoly than under monopoly.

As there is no perfect price discrimination, a bank may charge lower interest rates under monopoly than under competition. Therefore, a (local) monopoly's optimal pricing strategy consists in covering the market, until it faces a financial constraint. In contrast, under duopoly, banks are able at equilibrium to segment their markets between their closest insiders and their closest outsiders, and to extract higher rents. When switching and transportation costs are high enough, markets are highly segmented by the category of borrower under duopoly, such that a bailout may increase the interest rates.

5.3 The impact of a bailout policy on consumer surplus

In Proposition 7, we analyze the effect of a bailout policy on consumer surplus, both before and after a shock. In our model, consumer surplus is different from borrower surplus because some outsider consumers do not borrow if there is no bailout in the second period. We focus on consumer surplus to take this effect into account in our comparison. For this purpose, we denote by λ_{cs} the threshold on the financial constraint on banks such that a bailout policy may decrease consumer surplus ex post. The parameters s_{cs} and R_{cs} are defined such that the threshold λ_{cs} exists in the symmetric equilibrium of the game (see the Appendix D for their definitions).

Proposition 7. Ex ante, a bailout policy increases the average consumer surplus if it reduces first period interest rates, and it decreases the average consumer surplus otherwise. Ex post, a bailout policy always increases the average consumer surplus if the banking sector is vulnerable. If the banking sector is resilient, a bailout policy decreases the average consumer surplus if $s \geq s_{cs}$, $R \leq R_{cs}$ and $\lambda_{fc} \geq \lambda_{cs}$, and it increases the average consumer surplus otherwise.

Proof. Appendix D. ■

In the first period, since the market is covered, a bailout policy impacts consumer surplus only through its effect on the interest rates. Thus, consumer surplus increases if a higher probability of government intervention decreases the interest rates in the first period. The conditions for a reduction of the interest rates are given in Propositions 4 and 5.

In the second period, a bailout policy has three effects on consumer surplus: i) a price effect, ii) a market coverage effect and iii) a switching behavior effect. First, as seen in Proposition 6, a bailout policy may either increase or decrease prices in the second period of competition. Second, a bailout policy improves market coverage in the second period, since it prevents some borrowers from being left out of the credit market because of banks' financial constraints. This second effect increases consumer surplus. Third, a bailout impacts consumer switching behavior. Indeed, if the banking sector is resilient, it triggers switching by some borrowers who would have stayed with their home bank otherwise. However, poaching may lower consumer surplus if switching costs are high. If, in contrast, the banking sector is vulnerable, the bailout enables some borrowers to stay with their home bank instead of switching to the other bank to regain access to credit.

If the banking sector is vulnerable, the positive impact of the bailout on market coverage dominates all possible negative effects of a bailout on interest rates or switching costs. This positive impact is, however, decreasing with switching costs, because if both banks remain active, they do not fully compensate outside borrowers for their switching costs.

If the banking sector is resilient and the government decides not to intervene, the efficient rationing rule used by banks with financial constraints minimizes transportation costs, and no consumer incurs switching costs. In this case, credit rationing can be beneficial to borrowers if switching costs are high enough for two reasons. First, if switching costs are high, the bailout increases both interest rates on insiders and outsider borrowers, as explained in Proposition 6. Second, if switching costs are high, the bailout makes borrowers worse off by enabling poaching. In summary, if financial constraints on resilient banks are soft enough and the profitability of the project is low, a bailout policy decreases consumer surplus.

We also make a more precise analysis of the impact of bailout policies on consumers according to their switching behavior, which we summarize in Table 1 below. The sign (+) represents a positive effect of the bailout policy on borrower surplus (resp., (−) a negative effect), and ∅ is an empty set.[40] The last two lines indicate that the bailout either enables a group of consumers to regain access to credit (B => Credit) or to switch credit provider (B => Switching).

Table 1: impact of a bailout on borrower surplus

[40] If the banking sector is resilient, no borrower can switch unless the government provides liquidity support to banks.

[41] If switching costs are high, Propositions 4 and 5 imply that some borrowers in this category (including the indifferent borrower between staying and switching) are worse-off following a bailout.

[42] Idem

	Banking sector scenario	
Type of borrower	Resilient	Vulnerable
All	$(-)$ if $s > s_{cs}$, $R < R_{cs}$ and $\lambda_{fc} > \lambda_{cs}$	$(+)$
Always stay	$(-)$ if $s > s_r$ and $\lambda_{fc} > \lambda_i$	$(-)$ if $s > s_r$
Always switch	$\varnothing$	$(-)$ if $s > s_r$ and $\lambda_m > \lambda_o$
B => Credit	$(+)$	$(+)$
B => Switching	$(+)$ (on the aggregate surplus)[41]	$(+)$ (aggregate)[42]

5.4 The impact of a bailout policy on welfare

We now analyze whether a bailout policy increases social welfare, defined as the sum of banks' joint profit and consumer surplus. In the first period, since the market is covered and the interest rate is transferred from consumers to banks, total welfare is equal to the average benefit of credit for consumers (i.e., $R - t/4$), which is independent of the expected bailout policy. Therefore, it is interesting to analyze whether a bailout policy increases social welfare ex post and whether higher bailout expectations increase the expected social welfare ex ante.

The impact of a bailout policy on social welfare ex post

We analyze whether a bailout policy increases social welfare ex post. To proceed, it is useful to denote by ΔW_l the effect of the bailout policy on welfare, with $l = r$ if the banking sector is resilient, and $l = v$ if the banking sector is vulnerable. The effect ΔW_l can be decomposed as a function of Δu_l, the welfare gain from the returns of projects financed only under a bailout, Δt_l the difference in transportation costs and Δs_l the difference in switching costs, that is, we have

$$\Delta W_l = \Delta u_l + \Delta t_l + \Delta s_l, \tag{1.4}$$

where the expressions for Δu_l, Δt_l and Δs_l in equilibrium are given in Table 2.[43] In the equilibrium of the game, we have

	Banking sector in scenario l	
	Resilient $(l = r)$	Vulnerable $(l = v)$
Returns on projects Δu_l	$(1 - 2\lambda_{fc})R > 0$	$(1 - \lambda_m)R > 0$
Transportation costs Δt_l	$t\lambda_{fc}^2 - \frac{(11t^2 - 4st + 2s^2)}{36t}$	$t\lambda_m^2/2 - \frac{(11t^2 - 4st + 2s^2)}{36t}$
Switching costs Δs_l	$-s\frac{(t-s)}{3t}$	$-s(\frac{(t-s)}{3t} + 1/2 - \lambda_m)$

Table 2: decomposition of the effect of a bailout on social welfare

[43]See Appendix F for the expressions of Δu_l, Δt_l and Δs_l.

As seen in Table 2, the bailout has always a positive effect on the expansion of consumer access to credit ($\Delta u_l > 0$). However, its impact on consumer switching costs (Δs_l) may not always be positive because consumer mobility may either increase or decrease following a bailout. Moreover, the transportation costs (Δt_l) may also either increase or decrease.

If the banking sector is vulnerable, a bailout enables the government to save one bank and offer a full support to the banking sector. In that case, government intervention always increases social welfare ($\Delta W_v > 0$). The intuition of this result is due to resultant of the three effects that are detailed in Table 2. Suppose that the non-failing bank would have faced strong financial constraints, such that it would only serve a low proportion of the market without a bailout. In this case, the coverage effect of the bailout Δu_v is high, and it is neither offset by higher switching (Δs_v) nor transportation costs (Δt_v). On the contrary, if the non-failing bank would benefit from a high financial capacity, the allocation of credit would be less efficient than the bailout allocation due to high switching and transportation costs. Therefore, a bailout enhances welfare because it preserves market coverage while limiting inefficient mobility.

If the banking sector is resilient enough, a bailout may no longer provide the most efficient allocation of credit. Because the financial capacity λ_{fc} constrains both banks to serve only their respective insider markets, no consumer switches, while transportation costs are minimized.[44] Therefore, if the coverage effect is not too important, i.e., the profitability of the credit market is low enough (i.e., if R is below a threshold R_w), a bailout policy deteriorates welfare ex post.[45] The result also depends on the level of switching costs: if switching costs are high (and higher than a threshold s_w), a bailout may still be welfare-enhancing even if credit profitability is low.

We summarize the results on the impact of a bailout on social welfare ex post in Proposition 8.[46]

Proposition 8. If the banking sector is resilient, a bailout policy decreases social welfare ex post ($\Delta W_r < 0$) if either i) $R < R_w$ if $s < s_w$, or ii) $R < R_w$ and $\lambda_{fc} > \lambda_w$ if $s \geq s_w$. If the banking sector is vulnerable, a bailout policy increases social welfare ex post ($\Delta W_v > 0$).

Proof. Appendix E. □

[44] In our model, the transportation cost effect is minimized because the efficient rationing rule applies. However, even if the rule did not apply, the transportation cost effect of the bailout would still be strictly negative as long as constrained banks only serve their respective insider markets.

[45] This lower bound, defined such that a symmetric equilibrium of the game exists, equals $1 - s/t$ from (A6).

[46] For this purpose, we denote by λ_w the threshold on the financial constraint such that a bailout policy may decrease welfare ex post. The parameters s_w and R_w are defined such that this threshold λ_w exists in the symmetric equilibrium of the game (see the Appendix I for their definitions).

In Corollary 1, we detail the role of switching costs on the welfare effects of the bailout.

Corollary 1. When the banking sector is resilient or vulnerable, the benefits of a bailout on social welfare are increasing with switching costs, and they are more sensitive to switching costs when the banking sector is vulnerable.

Proof. Appendix F. □

If the banking sector is resilient, the bailout is more likely to be welfare-improving when switching costs are high. This result is caused by two effects. On the one hand, higher switching costs increase the costs of poaching per borrower if there is a bailout. On the other hand, higher switching costs decrease the measure of borrowers poached. Because we assumed that switching costs are higher than $t/2$ (see Assumptions (A2) and (A6)), the second effect dominates and both the transportation and switching costs effects of a bailout improve when switching costs increase.[47]

If the banking sector is vulnerable, the desirability of the bailout when switching costs are high is also reinforced by another effect. In this situation, higher switching costs also increase the costs of switching per borrower if there is no bailout, while the measure of borrowers who switch will be fixed by the financial constraint of the remaining bank.

The expected welfare effects of a bailout policy

The expected social welfare $E(W)$ is given by

$$E(W) = R - t/4 + \delta(\widetilde{p}_{ms} W_{ms} + \widetilde{p}_m W_m + \widetilde{p}_{fc} W_{fc}), \tag{1.5}$$

where W_h is the welfare with market structure $h \in \{ms, m, fc\}$ in the second period. In Appendix F, we show that a higher probability of government intervention (i.e., a higher β) increases the expected social welfare $E(W)$ if and only if

$$g(s) \equiv p_e W_{ms} - (\phi_m \Delta W_v + \phi_{fc} \Delta W_r) > 0, \tag{1.6}$$

where g is a convex polynomial function of degree 2. Thus, the total effect of the government intervention on the expected social welfare depends on how intervention changes banks' expectations regarding the future market structure (through ϕ_m and ϕ_{fc}), and whether this change is welfare-improving. As explained in our previous results, the bailout impacts borrower access to credit and their mobility, and may sometimes reduce welfare if the banking sector is resilient.

To limit the number of results that we present in the paper, we choose to focus on the case in which higher switching costs increase the marginal impact of a higher

[47] More generally, $\Delta t + \Delta s$ is decreasing with switching costs as long as $s > 2t/5$.

bailout probability β on the expected social welfare.[48] All other cases are presented in the Appendix F. In Proposition 9, we analyze how switching costs impact the effect of government intervention on the expected social welfare.

Proposition 9. Suppose that $9\phi_m(\alpha)(2\lambda_m - 1) < \phi_{ms}(\alpha)$ such that higher switching costs increase the marginal impact of a higher bailout probability on the expected social welfare.
i) If $g(t/2) \geq 0$, higher bailout expectations increase the expected social welfare.
ii) If $g(t/2) < 0$ and $g(t) > 0$, higher bailout expectations reduce the expected social welfare for low values of switching costs and increase the expected social welfare for high values of switching costs.
iii) If $g(t) < 0$, higher bailout expectations reduce the expected social welfare.

Proof. Appendix F. □

The result of Proposition 9 depends on whether higher bailout expectations increase or decrease the expected social welfare for high and low values of switching costs. Several cases may arise in our setting depending on banks' correlation of risks of failure and banks' expectations that their funding constraints will be fully relaxed by the government. We give below several examples to illustrate Proposition 9 in specific cases.

Examples: We characterize the impact of higher bailout expectations on the expected social welfare in four simple examples, in which the government support is either always partial ($\alpha = 0$) or total ($\alpha = 1$) and the correlation of banks' liquidity risks is either high (p_m close to 0) or low (p_e and p_{ms} close to 0). All proofs are available in the Appendix F of the paper.

- Low correlation of risks and partial support: In that case, government intervention prevents the emergence of a monopoly in the second period. Higher bailout expectations have two effects on the expected social welfare. First, government intervention enables a more efficient allocation of borrowers among banks. This first effect is positive. However, since the government does not fully relax banks' financial contraints, a countervailing effect arises which reduces welfare. This second effect may dominate the first. This happens if banks' lending capacities under a constrained duopolistic market structure λ_{fc} are low enough relative to the lending capacity of a monopoly λ_m, and if the profitability of credit market is high.[49] Therefore, even if switching costs are high, higher bailout expectations decrease welfare if a bailout does not relax enough the financial constraints of banks (i.e., case iii) of Proposition 9).

[48]This case arises when the intervention is expected to decrease the probability of monopolization.

[49]Hard financial constraints to supported banks relative to a monopoly may occur for instance if the monopoly benefits from efficiency gains or if it is identified by investors as too-big-to-fail following the failure of its competitor.

- Low correlation of risks and total support: A higher probability of government intervention always increases the expected social welfare (i.e., case i) of Proposition 9).
- High correlation of risks and partial support: In this situation, the government intervenes only when both banks risk to fail, which increases the expected social welfare (case i) of Proposition 9).
- High correlation of risks and full support: The intervention is now also triggered when both banks risk to face financial constraints, to protect market stability. Following Proposition 7, if switching costs are high, the intervention is likely to increase welfare in this situation. However, if banks face a high probability to compete with financial constraints, and a low probability to fail altogether, higher bailout expectations decrease welfare if switching costs are low (case ii) of Proposition 9).

6 Extensions and policy implications

In this section, we discuss the robustness of our results and the policy implications of the model

6.1 Banks' incentives to take risks

In the literature, higher bailout expectations may increase banks' incentives to take risks. In our setting, we have focused on liquidity risk. We therefore analyze the case in which investment in liquidity management is endogenous and discuss briefly the case of credit risk.

We endogenize banks' investment in liquidity management by assuming that higher investment in liquidity management increase the probability that the market structure remains stable in the second period. We also assume that the risk undertaken by banks remains unknown to borrowers. We denote the investment of bank $k \in \{A, B\}$ by z_k and banks' profit-maximizing level of investment in a symmetric equilibrium by z^*.

Proposition 10. A higher probability of government intervention β reduces banks' incentives to manage their liquidity needs cautiously (that is, we have $\partial z^* / \partial \beta \leq 0$) . Higher switching costs increase the marginal impact of government intervention on banks' investment in liquidity management.

Proof. See Appendix G. □

The intuition for this result is the following. The marginal effect of a higher investment in liquidity management on first period profits is positive, because banks reduce marginally more the discount offered to their consumers when they are more cautious and their bailout expectations increase (as $\partial^2 \widetilde{p}_{ms} / \partial z_k \partial \beta \leq 0$). Thus, banks have higher incentives to invest in liquidity management when their bailout expectations increase. This effect is increasing with switching costs (because the discount σ_{ms} is increasing with switching costs) and null if switching costs are close to zero.

The marginal effect of a higher investment in liquidity management on the expected second period profits is negative, because higher bailout expectations decrease the marginal probability that the market remains stable when banks are more cautious. Hence, banks have fewer incentives to invest in liquidity management when their bailout expectations increase. The magnitude of this second effect is increasing with switching costs, because the second period profit under market stability is increasing with switching costs (but less than the first effect). Since the second effect dominates the first, it follows that higher bailout expectations decrease banks' investment in liquidity management.

As regards credit risk, our framework does not allow us to endogenize banks'management of their lending portfolio in a simple way. However, we can conduct a first analysis of the relationship between banks' bailout expectations and the credit risk of their lending portfolio as follows. Banks may lend to riskier borrowers when their bailout expectations increase (i.e., that the borrower probability of success p may be decreasing with β), or reduce their screening efforts (i.e., the marginal cost of lending c may be decreasing with β).[50] In addition, the effect of higher bailout expectations on banks' funding costs is likely to be ambiguous because of moral hazard. The empirical evidence shows that market discipline may be eroded by bank bailouts such that funding costs may not reflect banks' risks accurately (Hett and Schmidt, 2013). This first analysis implies that adding endogenous credit risk would have an ambiguous effect on the net profitability of the credit market. If the net profitability of the credit market is reduced when bailout expectations increase, banks charge higher interest rates following a bailout. In that case, with endogenous credit risk, policies designed to reduce switching costs may become all the more necessary since there is a higher probability of government intervention (i.e., the threshold s_r of Proposition 4 may be reduced).

6.2 Market exit with a P&A transaction

When a bank fails, the remaining bank may sometimes engage in a Purchase and Assumption (P&A) transaction, such that it acquires all borrowers previously owned by its competitor.[51] Such a resolution method would impact our results as follows. If the government does not intervene, a P&A is concluded and no borrower incurs switching

[50] Assuming that banks may choose strategically the probability of default of their borrowers adds asymmetries in the first period in the Hotelling model of competition ithat make the model difficult to solve.

[51] In practice, a purchase and assumption agreement with a healthy bank is often a preferred option of the deposit insurance when available, because it allows continuation for depositors and most borrowers at little cost for the public budget.

costs because their accounts are transferred to the buyer.[52]

The effect of the bailout on the insiders remains unchanged. But now, a bailout always decreases the interest rates charged to outsiders. After a P&A agreement, the monopoly no longer needs to substract all switching costs from the interest rate of its outsiders, and therefore it extracts more rents. Compared to our baseline model, consumer surplus ex post does not change because borrowers were fully compensated for switching through discounted interest rates. Finally, a bailout remains welfare-enhancing because it provides full market coverage while limiting inefficient transportation costs. However, the difference with the monopoly situation is reduced if the P&A transaction purely eliminates the cost of switching incurred by borrowers and does not just transfer these costs from borrowers to another party during the transaction (the buyer, the failing bank or the government, depending on the price of purchase).

Ex ante, the effect on interest rates of a full-liquidity support of both banks may be reinforced. Now, each bank is willing to get a lower market share than its competitor, as there is a probability that it will become an acquirer with financial constraints.[53] However, this incentive implies that conditions for the uniqueness of a symmetric equilibrium of the game may no longer be fulfilled. Indeed, banks have incentives to set high first-period rates to maximize their benefits in case they become an acquirer. But if a bank with a dominant market share expects to be financially constrained in its insider market, it will not benefit from P&A opportunities to acquire outsider borrowers and does not set high first-period interest rates. Thus, an equilibrium of the game with asymmetric first-period interest rates and market shares may exist.

7 Conclusion

Bailout policies are expected to exert positive externalities on credit market interest rates and welfare, because they enable banks to remain competitive following liquidity shocks. In this article, we have shown that this intuition may not be robust to the introduction of switching costs and price discrimination, which are important determinants of competition in credit markets. Competing banks may take advantage of strategic complementaries and price discrimination to set high interest rates if switching costs are high, and they do not internalize the social costs of poaching. We stress nevertheless that lenient bailout policies

[52]We assume that the monopoly can still price discriminate between its first-period borrowers ("insiders") and the borrowers it purchases ("outsiders"), and that the transaction does not include the location of the failed bank. If the transaction does not eliminate switching costs, because, for instance, they only represent a psychological cost supported by borrowers, then there is no difference between our monopoly benchmark and a P&A.

[53]The discount $\overline{\sigma}$ in Proposition 2 becomes a premium when expected switching costs under monopoly are low enough. With null switching costs, the profit-maximizing share of insiders for a P&A bank equals half the market it can serve given its financial constraint, such that $\widetilde{x}_D = \lambda_m/2 < 1/2$.

also exert positive externalities on interest rates for naive new borrowers, by preserving banks' charter values.

One alley for future research is to understand how the effects of bailout policies could be modified by other frictions such as asymmetric information. Depending on their design and the nature of the shock, bailout policies can worsen or reduce adverse selection among banks, with unclear consequences on interest rates, rationing, and incentives to invest in lending relationships.

Bibliography

[1] Acharya, V., & Yorulmazer, T. 2007. Too many to fail - An analysis of time-inconsistency in bank closure policies. *Journal of Financial Intermediation,* 16(1), 1–31. doi:10.1016/j.jfi.2006.06.001

[2] Ahn, J-H., & Breton, R. 2014. Securitization, Competition and monitoring. *Journal of Banking & Finance*, 40(March), 195–210. doi:10.1016/j.jbankfin.2013.11.023

[3] Aliaga-Diaz, R., & Olivero, M. 2010. Is there a financial accelerator in US banking? Evidence from the cyclicality of banks' price–cost margins. *Economics Letters*, 108(2), 16–171. doi:10.1016/j.econlet.2010.04.037

[4] Barone, G., Felici, R., & Pagnini, M. 2011. Switching costs in local credit markets. *International Journal of Industrial Organization*, 29(6), 694–704. doi:10.1016/j.ijindorg.2011.03.004

[5] Beck, T., Coyle, D., Dewatripont, M., Freixas, X., & Seabright, P. 2010. Bailing out the banks: reconciling stability and competition. *Centre for Economic Policy Research, London.*

[6] Beggs, A. & Klemperer, P. 1992. Multi-period competition with switching costs. *Econometrica*, 651–666. doi:10.2307/2951587

[7] Benczur, P., Cannas, G., Cariboni, J., Di Girolamo, F., Maccaferri, S., & Giudici, M. P. 2017. Evaluating the effectiveness of the new EU bank regulatory framework: a farewell to bail-out? *Journal of Financial Stability*, 33, 207–223. doi:10.1016/j.jfs.2016.03.001

[8] Berger, A. N., Makaew, T., & Roman, R. A. 2019. Do Business Borrowers Benefit from Bank Bailouts? The Effects of TARP on Loan Contract Terms. *Financial Management*, 48(2), 575–639. doi:10.1111/fima.12222

[9] Berger, A. N., Roman , R. A. (2020). TARP and other bank bailouts and bail-ins around the world: Connecting Wall Street, Main Street, and the financial system. Academic Press. isbn: 0128138653

[10] Bergstresser, D. 2008. Banking Market Concentration and Consumer Credit Constraints: Evidence from the 1983 Survey of Consumer Finances. *SSRN Working Paper.* doi:10.2139/ssrn.1291354

[11] Bertsch, C., Calcagno, C., & Le Quement, M. 2015. Systematic Bailout Guarantees and Tacit Coordination. *B.E. Journal of Economic Analysis & Policy*, 15(1), 1–36. doi:10.1515/bejeap-2014-0027

[12] Bolton, P., Oehmke, M. 2019. Bank Resolution and the Structure of Global Banks. *Review of Financial Studies*, 32(6), 2384–2421. doi:10.1093/rfs/hhy123

[13] Bouckaert, J., & Degryse, H. 2004. Softening Competition by Inducing Switching in Credit Market. *Journal of Industrial Economics,* 52(1), 27–52. doi:10.1111/j.0022-1821.2004.00215.x

[14] Bouckaert, J., & Kort, P. M. 2014. Merger Incentives and the Failing Firm Defense. *Journal of Industrial Economics,* 62(3), 436–466. doi:10.1111/joie.12053

[15] Cabral, L., & Villas-Boas, M. 2005. Bertrand supertraps. *Management Science*, 51(4), 599-613. doi:10.1287/mnsc.1040.0313

[16] Cabral, L. 2016. Dynamic Pricing in Customer Markets with Switching Costs. *Review of Economic Dynamics*, 20, 43–62. doi:10.1016/j.red.2015.09.002

[17] Calderon, C., & Schaeck, K. 2016. The Effects of Government Interventions in the Financial Sector on Banking Competition and the Evolution of Zombie Banks. *Journal of Financial and Quantitative Analysis*, 51(4), 1391–1436. doi:10.1017/S0022109016000478

[18] Carbo-Valverde, S., Hannan, T. H., & Rodriguez-Fernandez, F. 2011. Exploiting old customers and attracting new ones: The case of bank deposit pricing. *European Economic Review*, 55(7), 903–915. doi:10.1016/j.euroecorev.2011.02.001

[19] Chevalier, J. A., & Scharfstein, D. S. 1996. Capital-Market Imperfections and Countercyclical Markups: Theory and Evidence. *American Economic Review*, 86(4), 703–725.

[20] Dam, L. & Koetter, M., 2011. Bank bailouts, interventions, and moral hazard. *SSRN Working Paper.* doi:10.2139/ssrn.2794065

[21] Degryse, H., & Ongena, S. 2008. Competition and Regulation in the Banking Sector: A Review of the Empirical Evidence on the Sources of Bank Rents. *Handbook of Financial Intermediation and Banking*, 483-554.

[22] Degryse, H., Kim, M., & Ongena, S. 2009. Microeconometrics of banking: methods, applications and results. *Oxford University Press.* isbn: 0195340477

[23] Degryse, H., Masschelein, N., & Mitchell, J. 2011. Staying, dropping, or switching: the impacts of bank mergers on small firms. *Review of Financial Studies*, 24(4), 1102–1140. doi:10.1093/rfs/hhp126

[24] Dell'Ariccia, M. G., & Ratnovski, M. L. 2013. Bailouts and systemic insurance. *International Monetary Fund*.

[25] Dimopoulos, T., & Schürhoff, N. 2021. Self-inflicted debt crises. *Swiss Finance Institute Research Paper Series*, 21(11).

[26] Dubé, J. P., Hitsch, G. J., & Rossi, P. E. 2009. Do switching costs make markets less competitive? *Journal of Marketing Research*, 46(4), 435-445. doi:10.1509/jmkr.46.4.435

[27] Fudenberg, D., & Tirole, J. 2000. Customer poaching and brand switching. *RAND Journal of Economics*, 31(4), 634–657. doi:10.2307/2696352

[28] Gehrig, T., & Stenbacka, R. 2007. Information sharing and lending market competition with switching costs and poaching. *European Economic Review,* 51(1), 77–99. doi:10.1016/j.euroecorev.2006.01.009

[29] Gropp, R., Hakenes, H., & Schnabel, I. 2011. Competition, risk-shifting, and public bail-out policies. *Review of Financial Studies,* 24(6), 2084–2120. doi:10.1093/rfs/hhq114

[30] Hakenes, H., & Schnabel, I. 2010. Banks without parachutes: competitive effects of government bail-out policies. *Journal of Financial Stability*, 6(3), 156–168. doi:10.1016/j.jfs.2009.05.006

[31] Hauswald, R., & Marquez, R. 2006. Competition and strategic information acquisition in credit markets. *Review of Financial Studies*, 19(3), 967–1000. doi:10.1093/rfs/hhj021

[32] Hett, F., & Schmidt, A. 2013. Bank bailouts and market discipline: how bailout expectations changed during the financial crisis. *Gutenberg School of Management and Economic*s, 1305.

[33] Ioannidou, V., & Ongena, S. 2010. "Time for a change": loan conditions and bank behavior when firms switch banks. *Journal of Finance,* 65(5), 1847–77. doi:10.1111/j.1540-6261.2010.01596.x

[34] Jeanne, O., & Korinek, A. 2019. Managing credit booms and busts: a Pigouvian taxation approach. *Journal of Monetary Economics*, 107, 2–17. doi:10.1016/j.jmoneco.2018.12.005

[35] Keeley, M. 1990. Deposit insurance, risk, and market power in banking. *American Economic Review,* 80(5), 1183–1200.

[36] Kim, M., Kliger, D., & Vale, B. 2003. Estimating switching costs: the case of banking. *Journal of Financial Intermediation,* 12(1), 25–56. doi:10.1016/S1042-9573(02)00005-0

[37] Klemperer, P. 1995. Competition when consumers have switching costs: An overview with applications to industrial organization, macroeconomics, and international trade. *Review of Economic Studies*, 62(4), 515–539. doi:10.2307/2298075

[38] Klemperer, P. 1987. The competitiveness of markets with switching costs. *RAND Journal of Economics*, 138–150. doi:10.2307/2555540

[39] Mandelman, F. S., Rabanal, P., Rubio-Ramirez, J. F., & Vilan, D. 2011. Investment-specific technology shocks and international business cycles: an empirical assessment. *Review of Economic Dynamics*, 14(1), 136–155. doi:10.1016/j.red.2010.08.001

[40] Neuberger, D., & Räthke, S. 2009. Microenterprises and multiple bank relationships: the case of professionals. *Small Business Economics,* 32(2), 207–29. doi:10.1007/s11187-007-9076-8

[41] OECD. 2009. Switching packs: an outline of country experiences. *OECD Working Party.*

[42] Ongena, S., & Smith, D. 2000. What determines the number of bank relationships? Cross-country evidence. *Journal of Financial Intermediation,* 9(1), 26–56. doi:10.1006/jfin.1999.0273

[43] Perotti, E. C., & Suarez, J. 2002. Last bank standing: what do I gain if you fail? *European Economic Review*, 46(9), 1599–1622. doi:10.1016/S0014-2921(02)00241-6

[44] Petersen, M. A., & Rajan, R. G. 1995. The effect of credit market competition on lending relationships. *The Quarterly Journal of Economics*, 110(2), 407–443. doi:10.2307/2118445

[45] Schwert, M. 2018. Bank capital and lending relationships. *Journal of Finance*, 73, 787–830. doi:10.1111/jofi.12604

[46] Shin, J., Sudhir, K. 2009. Switching costs and market competitiveness: deconstructing the relationship. *Journal of Marketing Research,* 46(4), 446–452. doi:10.1509/jmkr.46.4.446

[47] Shy, O. 2002. A quick-and-easy method for estimating switching costs. *International Journal of Industrial Organization,* 20(1), 71–87. doi:10.1016/S0167-7187(00)00076-X

[48] Skeel, D. A. 2014. When should bankruptcy be an option (for people, places or things)? *Faculty Scholarship at Penn Law*, 922.

[49] Stenbacka, R., & Takalo, T. 2019. Switching costs and financial stability. *Journal of Financial Stability*, 41, 14–24. doi:10.1016/j.jfs.2018.12.001

[50] Vickers, J. 2010. Central banks and competition authorities: institutional comparisons and new concerns," *Bank for International Settlements Working Paper,* 331.

[51] Vives, X. 2016. Competition and stability in banking: the role of regulation and competition policy. *Princeton University Press.* isbn:9780691171791

[52] Walther, A., & White, L. 2020. Rules versus discretion in bank resolution. *Review of Financial Studies*, 33(12), 5594–5629. doi:10.1093/rfs/hhaa032

[53] Von Weizsäcker, C. 1984. The costs of substitution. *Econometrica*, 52(5), 1085–1116. doi:10.2307/1910989

[54] Yanelle, M-O. 1997. Banking competition and market efficiency. *Review of Economic Studies*, 64(2), 215–239. doi:10.2307/2971710

Appendix

Appendix 0 - Summary of the variables used in the model

- Summary table:

Game Timing, Agents and Market structure	
$\tau = \{0, 1, 2\}$	Date
$l = \{1, 2\}$	Period of competition
$k = \{A, B\}$	Bank
$h \in \{ms,\ fc,\ m,\ e\}$	Market structure at $l = 2$, with ms: stable, fc: fin. constrained, m: monopoly, e: exit
Borrower characteristics	
p	Probability of project success / reimbursement
ρ	Return of project if successful, gross
R	Expected return of project, net of marginal cost of lending
t	Transportation costs
s	Switching cost
η	Proportion of myopic borrowers
δ^b	Borrower discount factor
Bank characteristics	
c	Marginal cost of lending
λ_h	Financial constraint
δ^{FI}	Bank discount factor
Credit market competition	
x_D	Indifferent borrower at $l = 1$
r_k^1	Interest rate at $l = 1$
$(r_k^i)^h$, $(r_k^o)^h$	Interest rate at $l = 2$ for insiders (resp. outsiders)
π_k, π_k^1, $(\pi_k^l)^h$	Bank profit (total-expected, at $l = 1$, at $l = 2$)
Market stability and bailout policy	
β	Proba. of any gov. intervention
α	Proba. of full-support, if the gov. intervenes
p_h	Proba. of market structure h without gov. interv.
$\widetilde{p}_h$	Proba. of market structure h, with possible gov. interv.
ϕ_h	Marginal effect of a higher probability of gov. interv. on p_h

- Banks' bailout expectations:

Banks expect *market stability* either if there is no government intervention and the market structure is stable (with probability p_{ms}) or if the market structure is unstable (with probability $1 - p_{ms}$), if the government intervenes (with probability β) and offers its full support to both banks (with probability α). Therefore, banks expect market stability to arise with probability

$$\widetilde{p}_{ms} = p_{ms} + (1 - p_{ms})\beta\alpha. \tag{1.7a}$$

Banks expect *competition with financial constraints* if either the market structure is a constrained duopoly after the liquidity shock (with probability p_{fc}) when the government does not offer its full support to both banks (with probability $1 - \beta\alpha$), or if the market structure is a monopoly after the liquidity shock (with probability p_m) and the government intervenes by offering its partial support to both banks (with probability $\beta(1 - \alpha)$). Therefore, banks expect competition with financial constraints to arise with probability

$$\widetilde{p}_{fc} = p_{fc}(1 - \beta\alpha) + p_m\beta(1 - \alpha), \tag{1.8}$$

Banks expect *monopolization* of the market by one bank if either there is no government intervention (with probability $1 - \beta$) and the market structure is a monopoly after the liquidity shock (with probability p_m), or if the government intervenes (with probability β) to prevent market exit of both banks (with probability p_e) by offering his support to one bank (with probability $1 - \alpha$). Therefore, banks expect monopolization to arise with probability

$$\widetilde{p}_m = p_m(1 - \beta) + p_e\beta(1 - \alpha). \tag{1.9a}$$

Banks expect to exit the market if the government does not intervene (with probability $1 - \beta$) after a systemic shock (with probability p_e). Therefore, banks expect *market exit* to arise with probability

$$\widetilde{p}_e = p_e(1 - \beta). \tag{1.10a}$$

Appendix A - Market coverage and profit-maximizing interest rates at $l = 2$
We analyze the interest rates charged by banks according to the market structure that prevails in the second period after the liquidity shock or the government intervention.

Market stability

Equilibrium under market stability If both banks remain in the market in the second period without financial constraints, borrowers can choose between staying with their initial bank and switching to its competitor.[54] We denote by $(x_k)^{ms}$ the indifferent borrower between staying with its first period bank k and switching to bank k'. The indifferent borrowers $(x_A)^{ms}$ and $(x_B)^{ms}$ are given by

$$(x_A)^{ms} = \frac{1}{2} + \frac{p[(r_B^o)^{ms} - (r_A^i)^{ms}] + s}{2t},$$

[54] Under Assumptions (A1)-(A5), we prove in the next section ("Market coverage") that all borrowers derive a positive utility from borrowing at the equilibrium of the game if both banks remain in the second period without financial constraints.

and

$$(x_B)^{ms} = \frac{1}{2} + \frac{p[(r_B^i)^{ms} - (r_A^o)^{ms}] - s}{2t}.$$

In the second period, each bank k chooses the interest rates $(r_k^i)^{ms}$ and $(r_k^o)^{ms}$ that maximize its profit in the second period given by

$$(\pi_k^2)^{ms} = (x_k^i)^{ms}(p(r_k^i)^{ms} - c) + (x_k^o)^{ms}(p(r_k^o)^{ms} - c), \tag{1.11}$$

where if $k = A$, we have $(x_A^i)^{ms} = (x_A)^{ms}$ and $(x_A^o)^{ms} = (x_B)^{ms} - x_D$. If $k = B$, we have $(x_B^i)^{ms} = 1 - (x_B)^{ms}$ and $(x_B^o)^{ms} = x_D - (x_A)^{ms}$.

Solving for the first-order conditions of profit maximization, we find that the interest rate charged to bank k's insider borrowers in the equilibrium of stage 2 is given by

$$(r_k^i)^{ms} = \frac{3c + 2t + s + p(r_{k'}^1 - r_k^1)}{3p}, \tag{1.12}$$

whereas the interest rate charged to bank k's outsider borrowers in the equilibrium of stage 2 is given by

$$(r_k^o)^{ms} = \frac{3c + t - s - p(r_{k'}^1 - r_k^1)}{3p}. \tag{1.13}$$

Bank k offers a discount to its outsider borrowers. From Eq.(1.12) and Eq.(1.13), this discount is equal to $(t + 2s)/(3p) - (r_k^1 - r_{k'}^1)$. It is decreasing with the size of bank k's initial market share, and increasing with the level of switching costs and borrower risk. Remarkably, the price charged to insider borrowers is twice as elastic to the degree of product differentiation as the price charged to outsider borrowers, reflecting the fact that a bank exerts a stronger market power on its insiders.

Substituting for $(r_k^i)^{ms}$ and $(r_k^o)^{ms}$ in Eq.(1.11), we find that the profit of bank k in the equilibrium of stage 2 is given by

$$(\pi_k^2)^{ms} = \frac{[2t + s + p(r_{k'}^1 - r_k^1)]^2}{18t} + \frac{[t - s - 2p(r_{k'}^1 - r_k^1)]^2}{18t}, \tag{1.14}$$

where the first part of $(\pi_k^2)^{ms}$ corresponds to the profit of bank k on its insider borrowers, and the second part corresponds to the profit of bank k on its outsider borrowers.

Market coverage under market stability At the equilibrium at $\tau = 2$ under unconstrained competition, poaching occurs for both banks if $(x_A)^{ms} < (x_D) < (x_B)^{ms}$. Also, the market is covered if the indifferent borrower between staying with one bank and switching derives a positive utility from borrowing, i.e., $p(\rho - (r_A^i)^{ms}) - t(x_A)^{ms} > 0$ and $p(\rho - (r_B^i)^{ms}) - t(1 - (x_B)^{ms}) > 0$. Replacing with $(r_k^i)^{ms}$ and $(r_k^o)^{ms}$ given in (1.12) and (1.13) in these conditions, we must have $|r_B^1 - r_A^1| < (t - s)/2p$ and $R > t + s/2 + p(|r_A^1 - r_B^1|)/2$. At symmetric equilibrium, these conditions hold from Assumptions (A1) and (A5).

Competition with financial constraints

If both banks compete with financial constraints, each bank k serves at most a measure λ_{fc} of consumers and makes a profit $(\pi_k^2)^{fc}$.[55] Their respective markets do not overlap and they enjoy local monopoly power over their borrowers. Depending on the severity of the funding constraints, banks renounce lending either to all their outsiders and some of their insiders, or only renounce lending to some of their outsiders (see Proof below).

If the constraint is severe (i.e., $\lambda_{fc} \leq x_D$), since the efficient credit rationing rule applies, bank A serves only its insiders. Bank A sets $(r_A^i)^{\underline{fc}} = (R - t\lambda_{fc})/p$, and it makes a profit

$$(\pi_A^2)^{\underline{fc}} = \lambda_{fc}(R - t\lambda_{fc}). \tag{1.15}$$

If the constraint is softer (i.e., $\lambda_{fc} \geq x_D$), bank A may serve both its insiders and outsiders. The bank chooses the interest rate $(r_A^i)^{\overline{fc}} = (R - tx_D)/p$ for its insiders and the interest rate $(r_A^o)^{\overline{fc}} = (R - s - t\lambda_{fc})/p$ for its outsiders, respectively. In that case, bank A makes a profit

$$(\pi_A^2)^{\overline{fc}} = \lambda_{fc}(R - t\lambda_{fc}) + (\lambda_{fc} - x_D)(tx_D - s). \tag{1.16}$$

Monopolization

If only bank k remains active with financial constraints, it serves at most a measure λ_m of its consumers and makes a profit $(\pi_k^2)^m$. Depending on the severity of the funding constraints, the bank renounces lending either to all its outsiders and some of its insiders, or only renounces lending to some of its outsiders (see Proof below).

If the constraint is severe (i.e., $\lambda_m \leq x_D$), bank A is constrained to serve only its insiders at a price $(r_A^i)^{\underline{m}} = (R - t\lambda_m)/p$. In that case, it makes a profit given by

$$(\pi_A^2)^{\underline{m}} = \lambda_m(R - t\lambda_m). \tag{1.17}$$

If the constraint is softer (i.e., $\lambda_m \in (x_D, \widehat{\lambda}_A)$, bank A serves its entire insider market x_D at a rate $(r_A^i)^m = (R - tx_D)/p$. It is, however, financially constrained in its outsider market, where it charges $(r_A^o)^{\overline{m}} = (R - s - t\lambda_m)/p$. It makes a profit given by

$$(\pi_A^2)^{\overline{m}} = \lambda_m(R - t\lambda_m) + (\lambda_m - x_D)(tx_D - s). \tag{1.18}$$

If the constraint is relaxed (i.e., $\lambda_m \geq \widehat{\lambda}_A$), bank A serves its entire insider market x_D at a rate $(r_A^i)^m = (p\rho - tx_D)/p$. It can maximize its profit on its outsider market, where it charges $(r_A^o)^{mu} = (p\rho + c - tx_D - s)/2p$. Its profit is given by

$$(\pi_A^2)^{mu} = x_D(R - tx_D) + (R - tx_D - s)^2/4t. \tag{1.19}$$

[55] This is due to Assumption (A2) and the efficient credit rationing rule.

Proof of equilibrium with financial constraints at $\tau = 2$ To reduce the number of cases considered, we will assume that first period interest rates are such that poaching arises at the equilibrium of the second period when there is no financial constraint. From Appendix A - Market coverage under market stability, this is equivalent to $|r_B^1 - r_A^1| < (t-s)/2p$, which implies that $x_D < (3t-s)/4t$.

From Assumption (A2), we know that if both firms are active and constrained, they always act as local monopolies, such that the only difference between the constrained duopoly and the monopoly case is the severity of the financial constraint. Therefore, we will first provide conditions for a (local) monopoly A with a general financial constraint $\lambda \in (0,1)$ to be constrained in its insider or outsider markets. We will then apply our results to the relevant cases under constrained duopoly and monopoly.

Let $(x_A^i) = p(\rho - r_A^i)/t$ (resp. $(x_A^o) = (p(\rho - r_A^o) - s)/t$) the insider (resp. outsider) borrower indifferent between borrowing from bank A and not borrowing. Let $(\widehat{x}_A^i)$ (resp. $\widehat{\lambda}_A$) the profit-maximizing value of (x_A^i) (resp. (x_A^o)) if a bank does not face any constraints in its insider (resp. outsider) market.

Let us first prove that $(\widehat{x}_A^i) > \min\{x_D, \lambda\}$, such that a bank is always constrained in its insider market by its financial constraint or its market share.

If this is not true, bank A is able to maximize its profit on its insider market given by

$$(\pi_A^i) = (x_A^i)(pr_A^i - c). \tag{1.20}$$

Taking the derivative of (1.20) with respect to (r_A^i), we find that bank A maximizes its profit by setting $r_A^i = (p\rho + c)/2p$. Replacing for r_A^i into (x_A^i), we find that $(\widehat{x}_A^i) = R/2t$. However, the necessary condition for this case, given by $R < 2tx_D$, always contradicts Assumption (A5). Indeed, we assumed $(3t-s)/4t > x_D$, such that $3t/2 - s/2 > 2tx_D > \underline{R}$. A bank is never able to maximize its profit in its insider market.

Let us now assume that $\widehat{\lambda}_A \in (x_D, \lambda)$ only if $\lambda = \lambda_m$, such that bank A may be able to maximize its profit on its outsider market only if bank A is a monopoly given by

$$(\pi_A^o) = (x_A^o - x_D)(pr_A^o - c). \tag{1.21}$$

Taking the derivative of (1.21) with respect to r_A^o, we find that bank A sets at equilibrium $r_A^o = (p\rho + c - tx_D - s)/2p$. Replacing for r_A^o into $\widehat{\lambda}_A$, we find that $\widehat{\lambda}_A = (R + tx_D - s)/2t$.[56]

First, this implies that $\widehat{\lambda}_A > \lambda_{fc}$ from (A3) and (A5). Second, this implies that $\widehat{\lambda}_A > x_D$ from (A5). Therefore, only a monopoly may be able to maximize its profit on its outsider market, if $\lambda_m > \widehat{\lambda}_A$.

[56] By symmetry, the constraint for bank B is given by $\lambda_m \leq \widehat{\lambda}_B$, with $\widehat{\lambda}_B = (R + t(1 - \widetilde{x}_D) - s)/2t$.

Appendix B - Market coverage and profit-maximizing interest rates at $l = 1$ Equilibrium of the game

In the first period, each bank k maximizes the expected discounted value of its profit $\pi_k = \pi_k^1 + E(\pi_k^2)$ with $E(\pi_k^2)$ given by Eq.(1.3) and π_k^1 given by Eq.(1.1).

If banks set symmetric interest rates in the first period, it must be that $x_D = 1/2$. From Assumptions (A2) and (A3), this implies that $\lambda_{fc} \leq x_D$ and $\lambda_m \in (x_D, \widehat{\lambda})$, with $\widehat{\lambda} = \widehat{\lambda}_A$ defined in Appendix A with $x_D = 1/2$. Therefore, from Appendix A, within $E(\pi_k^2)$ we have $(\pi_k^2)^{fc} = (\pi_k^2)^{\underline{fc}}$ given by Eq.(1.15), and $(\pi_k^2)^m = (\pi_k^2)^{\overline{m}}$ given by Eq.(1.18).

Around a symmetric equilibrium, the indifferent borrower in the first period x now forsees that: i) he will stay with his first period bank if it is the only one remaining in the market, ii) he will not regain access to credit if banks are both financially constrained, and iii) he will switch banks otherwise. By definition, the indifferent borrower in the first period x expects equal expected gains of credit access for both banks. We denote by $U_k(x)$ the total expected gain for the borrower in x if choosing bank k in the first period. The (forward-looking) indifferent borrower x is implicitly defined by

$$U_k(x) = U_{k'}(x), \tag{1.22}$$

where

$$\begin{aligned} U_k(x) &= p(\rho - r_k^1) - t(x) + \delta^b[p_{ms}(\widetilde{p}(\rho - (r_{k'}^o)^{ms}) - t(1-x) - s) \\ &\quad + \frac{\widetilde{p}_m}{2}(p(\rho - (r_k^i)^m) - tx + p(\rho - (r_{k'}^o)^{\overline{m}}) - t(1-x) - s], \end{aligned}$$

and $(r_{k'}^o)^{ms}$, $(r_k^i)^m$ and $(r_{k'}^o)^{\overline{m}}$ are given in Appendix A - Monopolization.

Solving in Eq.(1.22) for x, and replacing for $(r_k^i)^{ms}$ given in Eq.(3), for $(r_k^i)^m = (R - t\lambda_m)/p$ and $(r_k^o)^{\overline{m}} = (R - s - t\lambda_m)/p$, we find that

$$x = \frac{1}{2} - \frac{3(r_A^1 - r_B^1)}{t(6 + \delta^b(2\widetilde{p}_{ms} - 3\widetilde{p}_m))}$$

The total demand of bank A at $\tau = 1$ equals $x_D = \eta\, x|_{\delta^b=0} + (1-\eta)x$, and the total demand of bank B equals $1 - x_D$. Solving for the first-order conditions of banks' expected profits, we find that in the first period, each bank $k \in \{A, B\}$ charges the interest rate r_k^1 given in Proposition 3 (and the special case of Proposition 2) at $\tau = 1$.

In Online Appendix I, we show that the equilibrium of the game given in Proposition 3 (and the special case of Proposition 2) is unique.

Market coverage at $\tau = 1$ at the equilibrium of the game The utility of a borrower in the first period is decreasing with first period interest rates and transportation costs. From Proposition 3, first period interest rates are decreasing with the discounted probabilities $\delta^{FI}\widetilde{p}_m$, $\delta^{FI}\widetilde{p}_{ms}$ and $\delta^b\widetilde{p}_m$, and increasing with $\delta^b\widetilde{p}_{ms}$. To prove the market coverage at $\tau = 1$, and given that borrowers earn a non-negative utility at $t = 2$ (see Appendix A - Market coverage), it is therefore sufficient to show that the myopic indifferent borrower x_D between both banks at $\tau = 1$ derives a positive utility from borrowing when $\delta^{FI}\widetilde{p}_m$, $\delta^{FI}\widetilde{p}_{ms}$ and $\delta^b\widetilde{p}_m$ are minimum, i.e., $\delta^{FI}\widetilde{p}_m$ and $\delta^b\widetilde{p}_m$ equals 0, $\delta^{FI}\widetilde{p}_m = 1/2 + 3(1-\eta)\delta^b/(3+\delta^b\eta)$ from (A4), and $\delta^b\widetilde{p}_{ms} = 1$.

The utility of the indifferent borrower at $\tau = 1$ is equal to $p(\rho - r_A^1) - tx_D$, with $x_D = 1/2$ from Eq.(1.2) and $r_A^1 = r_B^1$ from Lemma 1. Replacing ${}^{FI}\widetilde{p}_m$, $\delta^{FI}\widetilde{p}_{ms}$, $\delta^b\widetilde{p}_m$ and $\delta^b\widetilde{p}_{ms}$ in r_A^1 by the values chosen above, Assumptions (A2) and (A6) implies that the utility of the indifferent borrower at $\tau = 1$ is higher than $R - (3t/2 - s/3)$, which is positive from (A5).

To conclude, the indifferent borrower derives a positive utility from borrowing at $\tau = 1$ for all parameters satisfying to Assumptions (A1)-(A6). This implies that at $\tau = 1$ the market is covered

Appendix C - Effect of bailout policy on second period interest rates We first analyze the effect of a bailout on interest rates for insiders in each banking sector scenario, before analyzing its effect on the interest rate charged to outsiders if the banking sector is vulnerable.

- Resilient banking sector (interest rate on insiders). From Proposition 1, we have at the symmetric equilibrium

$$(r_k^i)^{ms} - (r_k^i)^{\underline{fc}} = (t(2 + 3\lambda_{fc})/3 + s/3 - R)/p. \tag{1.23}$$

  Therefore, we have $(r_k^i)^{ms} \geq (r_k^i)^{\underline{fc}}$ if and only if $\lambda_{fc} \geq \lambda_i \equiv (R - 2t/3 - s/3)/t$. From (A3) and (A6), we assume $\lambda_{fc} \in (1 - s/t, 1/2)$. We have λ_i increasing in R, such that $\lambda_i \in (1 - s/t, 1/2)$ is equivalent to $R \in \{\underline{I}, \overline{I}\}$ with $\underline{I} = 5t/3 - 2s/3$ and $\overline{I} = 7t/6 + s/3$. We now determine whether $R \in \{\underline{I}, \overline{I}\}$ is possible given $R \geq \underline{R}$ from Assumption (A5).

Case 1. $s \in (t/2, 3t/5)$

In this case, we have $\underline{R} = 3t/2 - s/3$, such that $\underline{R} \in \{\underline{I}, \overline{I}\}$ is equivalent to $s > t/2$. This is always the case from (A2) and (A6). This implies that $R > \underline{I}$ under (A1)-(A6).

Case 2. $s \in (3t/5, t)$

In this case, we have $\underline{R} = t + s/2$, and $\underline{R} \in \{\underline{I}, \overline{I}\}$ equivalent to $s \in (4t/7, t)$. This is always true because $s \in (3t/5, t)$ in this case and $3t/5 > 4t/7$. Therefore, $R > \underline{I}$ under (A1)-(A6).

For convenience, we finally write $R < 7t/6 + s/3$ as $s \geq s_r$, with $s_r = 3R - 7t/2$.

To conclude, we have $(r_k^i)^{\underline{fc}} \leq (r_k^i)^{ms}$ if $s \geq s_r$ and $\lambda_{fc} \geq \lambda_i$ for all (R, λ_{fc}, s, t) satisfying to (A1)-(A6). In all other cases, we have $(r_k^i)^{\underline{fc}} \geq (r_k^i)^{ms}$.

- Vulnerable banking sector (interest rate on insiders). Our previous comparisons of interest rates for insider borrowers hold, except that now $\lambda_{fc} = 1/2$. Replacing for $\lambda_{fc} = 1/2$ into (1.23), we have that $(r_k^i)^m - (r_k^i)^{ms} = (R - 7t/6 - s/3)$. Therefore, if $s \geq s_r$, we have $(r_k^i)^m < (r_k^i)^{ms}$ for all (R, λ_{fc}, s, t) satisfying to (A1)-(A6), and $(r_k^i)^m > (r_k^i)^{ms}$ otherwise.
- Vulnerable banking sector (interest rate on outsiders). From Proposition 1, we have

$$(r_k^o)^{ms} - (r_k^o)^{\overline{m}} = (t(1 + 3\lambda_m)/3 + 2s/3 - R)/p,$$

where $\lambda_m \in (1/2, \min\left\{1, \overline{\lambda}_m\right\})$ from (A3). We have $(r_k^o)^{\overline{m}} \leq (r_k^o)^{ms}$ if and only if $\lambda_m \geq \lambda_o$, where $\lambda_o \equiv (R - t/3 - 2s/3)/t$. Therefore, there are three cases. In case 1, we have $\lambda_o \leq 1/2$. In case 2, we have $\lambda_o \in (1/2, \min\left\{1, \overline{\lambda}_m\right\})$. In case 3, we have $\lambda_o \geq \min\left\{1, \overline{\lambda}_m\right\}$.

Case 1. We have $\lambda_o \leq 1/2$ if and only if $R \leq 5t/6 + 2s/3$. This condition contradicts (A5).

Case 2. We have $\lambda_o \in (1/2, \min\{1, \lambda_m^c\})$. There are two cases according to the value of $\min\left\{1, \overline{\lambda}_m\right\}$. If $\min\left\{1, \overline{\lambda}_m\right\} = 1$, we have $R \geq 3t/2 + s$. We have $\lambda_o \leq 1$ if and only if $R \leq 4t/3 + 2s/3$. This contradicts $R \geq 3t/2 + s$, such that this case is impossible. If $\min\left\{1, \overline{\lambda}_m\right\} = \overline{\lambda}_m$, we have $R \leq 3t/2 + s$. We have $\lambda_o \leq \overline{\lambda}_m$ if and only if $R \leq 7t/6 + s/3$. We proved in *Case 2* above that this inequality does not contradict (A5).

Case 3. If $\lambda_o > \min\left\{1, \overline{\lambda}_m\right\}$, then $\lambda_o > \lambda_m$ and we have $(r_k^o)^{\overline{m}} \geq (r_k^o)^{ms}$. For convenience, we write $R < 7t/6 + s/3$ as $s \geq s_r$, with $s_r = 3R - 7t/2$.

To conclude, if $s \geq s_r$ and $\lambda_m > \lambda_o$, we have $(r_k^o)^{\overline{m}} < (r_k^o)^{ms}$ for all (R, λ_m, s, t) satisfying to (A1)-(A5). In all other cases, we have $(r_k^o)^{\overline{m}} > (r_k^o)^{ms}$.

Appendix D : Effect of bailout policy on second period consumer surplus

- If the banking sector is resilient, in a symmetric equilibrium, we have

$$CS_2^{ms} = p\rho - 2(\int_0^{(x_A^i)^{ms}} (p(r_k^i)^{ms}) + tx)\,dx + \int_{(x_A^i)^{ms}}^{x_D} (p(r_{k'}^o)^{ms} - t(1-x) - s)\,dx \quad (1.24)$$

and

$$CS_2^{\underline{h}} = \int_0^{\lambda_{fc}} (p(\rho - (r_k^i)^{\underline{fc}}) - tx)\,dx)$$

Replacing for $(r_k^i)^{ms}$, $(r_k^o)^{ms}$ and $(r_k^i)^{fc}$ given by Proposition 1, we have

$$CS_2^{ms} - CS_2^{h} = R - t\lambda_{fc}^2 - \frac{31t^2 + 16st - 2s^2}{36t}$$

Therefore, we have $CS_2^{ms} \geq CS_2^{fc}$ if and only if

$$R \geq R_{cs} = t\lambda_{fc}^2 + \frac{(31t^2 + 16st - 2s^2)}{36t}.$$

Case 1: $\underline{R} = 3t/2 - s/3$ (i.e., $s \leq 3t/5$)

We have $R_{cs} \geq \underline{R}$ if and only if $t^2(36\lambda_{fc}^2 - 23) + 28st - 2s^2 \geq 0$. From (A1), this polynomial function of degree 2 in λ_{fc} is positive if and only if $\lambda_{fc} \in [0, \lambda_{cs}^1]$, where $\lambda_{cs}^1 = \sqrt{23t^2 - 28st + 2s^2}/6t$. We have $\lambda_{cs}^1 \in [0, 1/2]$ if $s \in [t(7 - \sqrt{42}), 3t/5]$. Otherwise, we have $\lambda_{cs}^1 < 0$.

Case 2: $\underline{R} = t + s/2$

We have $R_{cs} \geq \underline{R}$ if and only if $t^2(36\lambda_{fc}^2 - 5) - 2st - 2s^2 \geq 0$. From (A1), this polynomial function of degree 2 in λ is positive if and only if $\lambda_{fc} \in [0, \lambda_{cs}^2]$, where $\lambda_{cs}^2 = \sqrt{5t^2 + 2st + 2s^2}/6t$. We have $\lambda_{cs}^2 \in [0, 1/2]$.

To conclude, we have $CS_2^{fc} \geq CS_2^{ms}$ only if $R \leq R_{cs}$, $s \geq t(7 - \sqrt{42})$ and $\lambda_{fc} \geq \lambda_{cs}$, with $\lambda_{cs} = \max\{\lambda_{cs}^1, \lambda_{cs}^2\}$. Otherwise, we have $CS_2^{fc} \leq CS_2^{ms}$.

- If the banking sector is vulnerable. In a symmetric equilibrium, we have

$$CS_2^{m} = \int_0^{x_D} (p(\rho - (r_k^i)^m) - tx)\,dx \int_{x_D}^{\lambda_m} (p(\rho - (r_k^o)^m) - tx - s)\,dx.$$

Replacing for $(r_k^i)^m$, $(r_k^o)^m$, $(r_k^i)^{ms}$ and $(r_k^o)^{ms}$ given in Proposition 1, with CS_2^{ms} defined in Eq.(1.24), we have

$$CS_2^{ms} - CS_2^{m} = R - t\lambda_m(1 - \lambda_m) - \frac{31t^2 + 16st - 2s^2}{36t} \tag{1.25}$$

From (A3), we have $\lambda_m \leq \min\left\{1, \overline{\lambda}_m\right\}$. We have $\partial(CS_2^m - CS_2^{ms})/\partial\lambda_m = t(\lambda_m - 1/2) \geq 0$ from (A3) and (A5). We now prove that even at the maximum of λ_m given by $\min\left\{1, \overline{\lambda}_m\right\}$, we have $CS_2^m < CS_2^{ms}$. There are two cases.

Case 1: $\min\left\{1, \overline{\lambda}_m\right\} = 1$ (i.e., $R > 3t/2 + s$).

Replacing λ_m by 1 in (1.25), we have $CS_2^m - CS_2^{ms}|_{\lambda_m=1} = 10t/9 + 4s/9 - s^2/18t - R$. This is always negative since we assume that $R > 3t/2 + s$.

Case 2: $\min\left\{1, \overline{\lambda}_m\right\} = \overline{\lambda}_m$ (i.e., $R < 3t/2 + s$). Replacing λ_m by $\overline{\lambda}_m$ in (1.25), we have

$$CS_2^m - CS_2^{ms} = \frac{(R - s - 11t/2)(R - s - 7t/2) - (4/9)(s + 5t)^2}{8t}$$

Therefore, $CS_2^m - CS_2^{ms}$ is a convex polynomial function of degree 2 in R. We denote by $\{R^1_{csm}, R^2_{csm}\}$ the two roots of the equation $CS_2^{mu} - CS_2^{ms} = 0$. We have

$$R^1_{csm} = s + 9t/2 - (1/3)\sqrt{4s^2 + 40st + 109t^2},$$

and

$$R^2_{csm} = s + 9t/2 + (1/3)\sqrt{4s^2 + 40st + 109t^2}.$$

We start by proving that $R^1_{csm} < \underline{R}$. This is true if $R^1_{csm} < t + s/2$, which simplifies to $(7s - t)(s + 5t) > 0$. This inequality is always true from (A1) and (A6). Also, we observe that $R^2_{csm} > \underline{R}$. However, we have $R^2_{csm} > 3t/2 + s$. Therefore, in Case 2, we have $R \in (R^1_{csm}, R^2_{csm})$.

To conclude, we always have $CS_2^m < CS_2^{ms}$.

Appendix E : Effect of bailout policy on second period social welfare

- If the banking sector is resilient, in a symmetric equilibrium, the difference in welfare is given by

$$\Delta W_r = 2\left(\int_0^{(x_A)^{ms}} (R - tx)\,dx + \int_{(x_A)^{ms}}^{x_D} (R - t(1-x) - s)\,dx\right) - \int_0^{\lambda_{fc}} (R - tx)\,dx).$$

Replacing $(r_k^i)^{ms}$ and $(r_k^o)^{ms}$ given in Proposition 1 into $(x_A)^{ms}$, and replacing x_D by 1/2 from Lemma 1, we have

$$\Delta W_r = (1 - 2\lambda_{fc})R + t\lambda_{fc}^2 - \frac{11t^2 + 8st - 10s^2}{36t}.$$

Therefore, ΔW_r is negative if and only if

$$R \leq R_w = \frac{t^2(11 - 36\lambda_{fc}^2) + 8st - 10s^2}{36t(1 - 2\lambda_{fc})}.$$

We now compare R_w to $\underline{R}$ given by (A5).

Case 1: if $s < 3t/5$, we have $\underline{R} = 3t/2 - s/3$. Therefore, the inequality $R_w \geq \underline{R}$ is equivalent to $-36t^2\lambda_{fc}^2 + 12\lambda_{fc}t(9t-2s) - 43t^2 + 20st - 10s^2 \geq 0$. This inequality holds if $\lambda_{fc} \in [\lambda_{w1}, 1/2]$ from (A3). Indeed, the polynomial function of degree 2 in λ_{fc} admits two roots denoted by $\lambda_{w1} = 3/2 - (1/3t)(s + (\sqrt{2}/2)\sqrt{19t^2 - 8st - 3s^2}) \in [0, 1/2]$ from (A1) and $\lambda_{w2} > 1/2$. Also, we always have $\lambda_{fc} > \lambda_{w1}$ given (A6) if $\lambda_{w1} < 1 - s/t$, i.e $s < t(\sqrt{519/2} - 10)/11 < 3t/5$.

Case 2: if $s > 3t/5$, $\underline{R} = t + s/2$. The inequality $R_w \leq \underline{R}$ is equivalent to $36(-t^2\lambda_{fc} + \lambda_{fc}t(s+2t)) - 5(5t^2 + 2st + 2s^2) \geq 0$. It admits two roots denoted by λ_{w3} and λ_{w4}, with $\lambda_{w3} = 1 + s/2t - (\sqrt{11t^2 + 26st - s^2})/6t \in [0, 1/2]$ and $\lambda_{w4} > 1/2$ from (A1). Therefore, $R_w \geq \underline{R}$ is equivalent to $\lambda_{fc} \in [\lambda_{w3}, 1/2]$. Also, we have $\lambda_{fc} > 1 - s/t$ from (A6), and $\lambda_{w3} < 1 - s/t$ if $s < t(13 + 3\sqrt{119})/82 < 3t/5$, such that $\lambda_{w3} > 1 - s/t$ in Case 2.

To conclude, $\Delta W_r \geq 0$ only if $R \geq R_\pi$ and either $s < t(\sqrt{519/2} - 10)/11$ or $\lambda_{fc} \geq \lambda_w$ with $\lambda_w = \max\{\lambda_{w1}, \lambda_{w3}\}$.

- If the banking sector is vulnerable, in a symmetric equilibrium, the difference in welfare is given by

$$\Delta W_v = 2\left(\int_0^{(x_A)^{ms}} (R - tx)\,dx + \int_{(x_A)^{ms}}^{x_D} (R - t(1-x) - s)\,dx\right) - \left(\int_0^{\lambda_m} (R - tx)\,dx - \int_{x_D}^{\lambda_m} s\,dx\right) \tag{1.26}$$

In Eq.(1.26), we replace $(r_k^i)^{ms}$ and $(r_k^o)^{ms}$ given in Proposition 1 into $(x_A)^{ms}$ and x_D by 1/2 from Lemma 1. We have
$\partial(\Delta W_v)/\partial\lambda_m = -R + s + t\lambda_m$. We now prove that even at the maximum of λ_m given by $\min\left\{1, \overline{\lambda}_m\right\}$ from (A3), we have $\partial(\Delta W_v)/\partial\lambda_m < 0$ and $\Delta W_v > 0$. There are two cases.

Case 1: $\min\left\{1, \overline{\lambda}_m\right\} = 1$ (i.e $R > 3t/2 + s$).

Since $R > 3t/2 + s$, we have $\partial(\Delta W_v)/\partial\lambda_m = -R + s + t < 0$. From (1.26), we have $\Delta W_v|_{\lambda_m=1} = (7t^2 + 10s^2 + 10st)/36t > 0$.

Case 2: $\min\left\{1, \overline{\lambda}_m\right\} = \overline{\lambda}_m$ (i.e $R < 3t/2 + s$).

We have $\partial(\Delta W_v)/\partial\lambda_m = -R + s + t/2 < 0$ from (A5). Replacing λ_m by $\overline{\lambda}_m$ in (1.26), we have

$$\Delta W_v|_{\lambda_m = \overline{\lambda}_m} = \frac{17t^2 + 20(st + s^2) - 27(R - s - 7t/6)^2}{72t}.$$

Solving for R, we have $\Delta W_v|_{\lambda_m = \overline{\lambda}_m} < 0$ if and only if

$$R > R_{Wv} = 7t/6 + s + \sqrt{17t^2 + 20(st + s^2)}/(3\sqrt{3}).$$

We have $R_{Wv} > 3t/2 + s$ if and only if $42t^2 + 60(st + s^2) > 0$, such that $R_{Wv} > 3t/2 + s$. Therefore, in Case 1 as in Case 2, $R < R_{Wv}$ and ΔW_v is always positive.

Appendix F - Effect of bailout policy on the expected social welfare

Definitions of Δt, Δs and Δu at the equilibrium of the game

$$\Delta u_r = \int_0^1 R dx - 2\int_0^{\lambda_{fc}} R dx \textbf{ and } \Delta u_v = \int_0^1 R dx - \int_0^{\lambda_m} R dx.$$

$$\Delta t_r = 2\left(\int_0^{(x_A)^{ms}} (-tx)dx + \int_{(x_A)^{ms}}^{1/2} -t(1-x)dx\right) - 2\int_0^{\lambda_{fc}} (-tx)dx.$$

$$\Delta t_v = 2\left(\int_0^{(x_A)^{ms}} (-tx)dx + \int_{(x_A)^{ms}}^{1/2} -t(1-x)dx\right) - \int_0^{\lambda_m} (-tx)dx.$$

$$\Delta s_r = -2\left(\int_{(x_A)^{ms}}^{1/2} (-s)dx \textbf{ and } \Delta s_v = 2\int_{(x_A)^{ms}}^{1/2} (-s)dx - \int_{1/2}^{\lambda_m} (-s)dx.\right.$$

Replacing $(x_A)^{ms}$ with $(r_k^i)^{ms}$ and $(r_k^o)^{ms}$ given by Proposition 1, we derive the results in the text.

Proof of Corollary 1 For $l \in \{r, v\}$, replacing for ΔW_l given in Eq.(1.4), with Δu_l, Δt_l and Δs_l given in the text, we find that

- If the banking sector is resilient ($l = r$): $\partial \Delta W_r/\partial s = (10s - 4t)/18t > 0$ from (A2) and (A6).
- If the banking sector is vulnerable ($l = v$):

$\partial \Delta W_v/\partial s = \lambda_m + (10s - 13t)/18t > 0$ from (A2), (A3) and (A6),

and $\partial \Delta W_v/\partial s - \partial \Delta W_r/\partial s = \lambda_m - 1/2 > 0$ from (A3).

Proof of Proposition 9 Replacing for $\widetilde{p}_{ms}$, $\widetilde{p}_m$ and $\widetilde{p}_{fc}$ into $E(W)$ given in Eq.(1.5), and taking the derivative of $E(W)$ with respect to β, we have that $\partial E(W)/\partial\beta > 0$ if and only if

$$\phi_{ms} W_{ms} + \phi_m W_m + \phi_{fc} W_{fc} > 0. \tag{1.27}$$

Replacing for $\phi_h(\alpha) = (\widetilde{p}_h(\beta, \alpha) - p_h)/\beta$, with $\widetilde{p}_{ms}$, $\widetilde{p}_m$, $\widetilde{p}_{fc}$ given in Eqs.(1.7a)-(1.9a) and $p_e + p_m + p_{ms} + p_{fc} = 1$, we have $p_e = \phi_{ms} + \phi_m + \phi_{fc}$. Replacing for $\phi_{ms} = p_e - \phi_m - \phi_{fc}$ into (1.27), the inequality of Eq. (1.27) is equivalent to Eq.(1.6). Replacing for $\phi_{fc} = p_e - \phi_{ms} - \phi_m$ into g given in Eq.(1.6), the function g can be rewritten as

$$g(s) = \Delta W_r(\phi_{ms} + \phi_m) - \Delta W_v \phi_m + p_e W_{fc}. \tag{1.28}$$

We now study the sign of $g(s)$ for $s \in (t/2, t)$, which is a polynomial function of degree 2 in s. The sign of $g(t/2)$ is either positive of negative. For example, if $\alpha = 0$ and $p_e = 0$, we have $g(t/2) = \phi_m(W_m - W_{fc})$, which can be positive or negative depending on λ_m and λ_d.

To study the sign of g, we examine whether g is increasing with s. Taking the derivative of Eq (1.28) with respect to s, we find that

$$g'(s) = \frac{\phi_{ms}(10s - 4t) - 9\phi_m(2\lambda_m - 1)}{18t}.$$

Since $\phi_{ms} > 0$, we have $g^{(2)}(s) = 5\phi_{ms}/(9t) > 0$. Therefore, g is convex in s and g is U-shaped. Since $\phi_{ms} > 0$, we have $g'(s) > 0$ if and only if

$$s > t(\frac{2}{5} + \frac{9\phi_m(2\lambda_m - 1)}{10\phi_{ms}}).$$

From Assumptions (A2) and (A6), we have $s > t/2$. We define the threshold

$$\widetilde{s} \equiv \min\{t, \max\left\{t(\frac{2}{5} + \frac{9\phi_m(2\lambda_m - 1)}{10\phi_{ms}}), \frac{t}{2}\right\}\}.$$

We have $\widetilde{s} = t/2$ if and only if $\phi_{ms} > 9\phi_m(2\lambda_m - 1)$, and $\widetilde{s} = t$ if $\phi_{ms} < 3(\lambda_m - 1/2)\phi_m(\alpha)$.

If $\widetilde{s} = t/2$, we have $g'(s) > 0$ for all $s \in (t/2, t)$. If $g(t/2) > 0$, then $g(s)$ is positive for all $s \in (t/2, t)$. In that case, a higher probability of government intervention increases the expected social welfare. If $g(t/2) < 0$ and $g(t) > 0$, there exists a level of switching costs s_E such that $g(s)$ is negative for $s \in (t/2, s_E)$ and $g(s)$ is positive for $s \in (s_E, t)$. In that case, a higher probability of government intervention reduces social welfare for low values of switching costs and increases social welfare for higher values of switching costs. If $g(t) < 0$, the function $g(s)$ is negative for all $s \in (t/2, t)$, and a higher probability of government intervention always reduces social welfare.

If $\widetilde{s} = t(2/5 + 9\phi_m(2\lambda_m - 1)/\phi_{ms})$, we have $g'(s) < 0$ for $s \in (t/2, \widetilde{s})$ and $g'(s) > 0$ for $s \in (\widetilde{s}, t)$.

If $g(t/2) < 0$, the function g is decreasing and then increasing in s. If $g(t) < 0$, the function g is decreasing in s. The function g is always negative. Thus, in that case, a higher probability of government intervention reduces the expected social welfare. If $g(t) > 0$ and $g(t/2) < 0$, there exists a threshold level of switching costs that we also denote by s_E such that $g(s)$ is negative for $s \in (t/2, s_E)$ and $g(s)$ is positive for $s \in (s_E, t)$. In that case, a higher probability of government intervention reduces social welfare for low values of switching costs and increases social welfare for higher values of switching costs.

If $g(t/2) > 0$, we need to determine the sign of $g(\widetilde{s})$ to conclude. If $g(\widetilde{s}) > 0$, then $g(s)$ is positive for all $s \in (t/2, t)$. A higher probability of government intervention increases social welfare. If $g(\widetilde{s}) < 0$ and $g(t) > 0$, there exists two levels of switching costs s_e and s_E such that $g(s)$ is positive for $s \in (t/2, s_e)$, negative for $s \in (s_e, s_E)$, and positive for $s \in (s_E, t)$. In that case, a higher probability of government intervention increases social welfare for low and high values of switching costs and decreases it otherwise. If $g(\widetilde{s}) < 0$ and $g(t) < 0$, there exists one level of switching costs s_e that $g(s)$ is negative for $s \in (t/2, s_e)$ and positive for $s \in (s_e, t)$. In that case, a higher probability of government intervention decreases social welfare for low values of switching costs and then increases social welfare for high values of switching costs.

Proofs of examples. *Low correlation of risks and partial support***.** If $\phi_{ms} = p_e = 0$ and $\phi_m = -p_m$, the condition in Proposition 9 (i.e., $9\phi_m(2\lambda_m - 1) < \phi_{ms}$) is verified, such that g is increasing with s. Also, $g(t)$ in Eq (1.28) equals $p_m(\Delta W_v - \Delta W_r)$, which is a polynomial of degree 2 in λ_{fc}, where $-tp_m$ is the coefficient of λ_{fc}^2. Its roots are given by λ_{fc}^a and λ_{fc}^b, such that

$$\lambda_{fc}^a = \frac{1}{2t}(2R - \sqrt{4R^2 - 4t\lambda_m(R-t) - 2t^2(1-\lambda_m^2)}).$$

We have $\lambda_{fc}^a \in (0, 1/2)$ and $\lambda_{fc}^b > 1/2$ from Assumptions (A3) and (A5). Because g is increasing with s, $g(s) < g(t) < 0$ if $\lambda_{fc} \in (0, \lambda_{fc}^a)$.

*Low correlation of risks and total support***.** If $\phi_{ms} = p_m$, $p_e = 0$ and $\phi_m = -p_m$, we have $g(t/2) = p_m \Delta W_v$, which is positive from Proposition 8.

High correlation of risks and partial support. With $\phi_{ms} = 0$ and $\phi_m = p_e$, we have $g(t/2) = p_e(\Delta W_r - \Delta W_v + W_{fc})$, which simplifies to $p_e W_m > 0$ by definition of ΔW_r and ΔW_v.

High correlation of risks and full support. If $\phi_{ms} = p_e + p_h$ and $\phi_m = 0$, we have $g(s) = p_e(\Delta W_r + W_{fc}) + p_h \Delta W_r$, which simplifies to $p_e W_{ms} + p_h \Delta W_r$ by definition of ΔW_r. Also, this verifies the condition in Proposition 9 given by $9\phi_m(2\lambda_m - 1) < \phi_{ms}$, such that g is increasing with s.

For $s = t$, we have $\Delta W_r = R(1 - 2\lambda_{fc}) - t(1 - 4\lambda_{fc}^2)/4$, which is positive if $R > t(1 + 2\lambda_{fc})/4$. This inequality holds from Assumptions (A2) and (A5). Thus, because $W_{ms} > 0$ for all s, we have $g(t) > 0$.

We have $g(t/2) = p_h t \lambda_{fc}^2 - 2Rp_h\lambda_{fc} + (p_e + p_h)(R - 25t/72)$. Its roots are given by λ_{fc}^c and λ_{fc}^d, where

$$\lambda_{fc}^c = \frac{1}{p_h t}(p_h R - \sqrt{p_h(p_h R^2 - t(p_e + p_h)(72R - 25t))}).$$

We have $\lambda_{fc}^d > 1/2$ from Assumption (A5) and $\lambda_{fc}^c \in (0, 1/2)$ if $R < (25p_e + 7p_h)t/72p_e$, and $\lambda_{fc}^c > 1/2$ otherwise.

At $s = t/2$, Assumption (A5) equals $R > 4t/3$. Therefore, $\lambda^c_{fc} \in (0, 1/2)$ does not contradict Assumption (A5) if $p_e < 7p_h/71$.

To conclude, if $p_e < 7p_h/71$ and $R < (25p_e + 7p_h)t/72p_e$ and $\lambda_{fc} > \lambda^c_{fc}$, we have $g(t/2) < 0$, and there exists a level of switching costs s_E such that $g(s)$ is positive if and only if $s > s_E$. In all other cases, $g(s)$ is positive for all levels of switching costs.

Appendix G: Switching costs and banks' incentives to take risks We endogenize banks' investment in liquidity management. Banks may invest to manage their liquidity risk more cautiously, such that it increases the probability that the market remains stable before the first period of competition.[57] To proceed, it is useful to formalize additional notation first. We denote by z_k the investment that bank k makes to manage its liquidity risk cautiously and we assume that the probability that the market remains stable depends on both banks' investment (i.e., $p_{ms}(z_A, z_B)$). Each bank incurs a cost $C(z_k)$ when it invests to manage its liquidity risk, where $C(0) = 0$, $C'(z_k) \geq 0$ and $C''(z_k) \geq 0$.

This extension enables us to discuss in a very simple framework how the interplay of switching costs and bailout expectations could impact banks' incentives to take risks. When bank k is more cautious (i.e., when z_k increases), the probability that the market remains stable increases concavely, that is, $\partial p_{ms}(z_A, z_B)/\partial z_k \geq 0$ and $\partial^2 p_{ms}(z_A, z_B)/\partial z_k^2 \leq 0$ for all $k \in \{A, B\}$. Thus, a higher bailout expectations decrease the marginal impact of z_k on the probability that the market remains stable (i.e., that is, we have $\partial^2 \widetilde{p}_{ms}/\partial z_k \partial \beta = -\alpha \partial p_{ms}(z_A, z_B)/\partial z_k \leq 0$).

Higher bailout expectations impact banks' marginal benefits of being cautious when they manage their liquidity needs as follows. Banks choose their level of cautiousness according to their trade-off between first and second period profits. We denote by z^* the level of investment in liquidity management chosen by banks in a symmetric equilibrium.

We show that, at interest rates given in Proposition 2, π_k the total expected profit of bank k is concave in z_k. Replacing π_k by $\pi^1_k + \delta E(\pi^2_k)$, with $\pi^1_k = (1/2)(pr^1_k - c)$ and $\partial p_m/\partial z_k = \partial p_{fc}/\partial z_k = 0$, banks' profits are concave in z_k if

$$\left.\frac{\partial^2 \pi_k}{\partial z_k^2}\right|_{z^*} = K = \delta \left.\frac{\partial^2 \widetilde{p}_{ms}}{\partial z_k^2}\right|_{z^*} (\pi^2_{ms} - \frac{s}{3}) - C''(z^*) < 0. \tag{1.29}$$

We have $\partial^2 p_{ms}(z_A, z_B)/\partial z_k^2 \leq 0$ and $C''(z^*) > 0$. Replacing π^2_{ms} by Eq.(1.14) at the symmetric equilibrium, $\pi^2_{ms} > s/3$ if and only if $5t^2 - 4st + 2s^2 > 0$, which is always true from Assumption (A1). Therefore, banks' profits are concave in z_k.

[57] In this extension, we assume that a higher level of investment in liquidity management has no impact on the probability of monopolization nor on the probability that banks compete with financial constraints in the second period.

We analyze how higher bailout expectations impact banks' incentives to invest in liquidity management. From the implicit function theorem, we have that

$$\partial z^*/\partial\beta = -(\partial^2\pi_k/\partial z_k^2\Big|_{z^*})^{-1}(\partial^2\pi_k/\partial z_k\partial\beta\Big|_{z^*}).$$

Since π_k is concave in z_k, we conclude that $\partial z^*/\partial\beta$ has the sign of $\partial^2\pi_k/\partial z_k\partial\beta|_{z^*}$.

We now analyze the sign of $\partial^2\pi_k/\partial z_k\partial\beta|_{z^*}$. Since $\pi_k = \pi_k^1 + \delta E(\pi_k^2)$ and $\pi_k^1 = (1/2)(pr_k^1 - c)$, we have

$$\frac{\partial^2\pi_k}{\partial z_k\partial\beta}\Bigg|_{z^*} = \frac{p}{2}\,\frac{\partial^2 r_k^1}{\partial z_k\partial\beta}\Bigg|_{z^*} + \delta\,\frac{\partial^2 E(\pi_k^2)}{\partial z_k\partial\beta}\Bigg|_{z^*}.$$

From the definition of r_k^1 given in Proposition 2, since $\widetilde{p}_{ms} = p_{ms} + \alpha\beta(1 - p_{ms})$ and $\partial p_m/\partial z_k = \partial p_{fc}/\partial z_k = 0$, we have

$$\partial^2 r_k^1/\partial z_k\partial\beta = \alpha\delta(2s/3p)(\partial p_{ms}/\partial z_k).$$

Moreover, from the definition of $E(\pi_k^2)$ in Eq.(1.3), we have $\partial^2 E(\pi_k^2)/\partial z_k\partial\beta = -\alpha\pi_{ms}^2(\partial p_{ms}/\partial z_k)$. This implies that

$$\frac{\partial^2\pi_k}{\partial z_k\partial\beta}\Bigg|_{z^*} = J = -\delta\alpha\frac{\partial p_{ms}}{\partial z_k}(\pi_{ms}^2 - \frac{s}{3}). \tag{1.30}$$

We already showed that $\pi_{ms}^2 > s/3$ in Eq.(1.29). Together with $\delta\alpha(\partial p_{ms}/\partial z_k) > 0$, this implies that $\partial^2\pi_k/\partial z_k\partial\beta < 0$. Hence, we have $\partial z^*/\partial\beta < 0$. Hence, we conclude that higher bailout expectations decrease banks' level of investment in liquidity risk management.

Finally, we study how switching costs impact the marginal impact of higher bailout expectations on banks' investment in liquidity risk management, that is, we analyze how $\partial z^*/\partial\beta$ varies with s. We have $\partial z^*/\partial\beta = -J/K$. Moreover, we denote by $L = -2(t-s)/9t$ the derivative of $\pi_{ms}^2 - s/3$ with respect to s, which is negative from Assumption (A1). The sign of $\partial z^*/\partial s\partial\beta = \partial(-J/K)/\partial s$ at $z_k = z^*$ is the sign of $J(\partial K/\partial s) - K(\partial J/\partial s)$, where $\partial K/\partial s = \delta(\partial^2\widetilde{p}_{ms}/\partial z_k^2)L$ and $\partial J/\partial s = -\delta\alpha(\partial p_{ms}/\partial z_k)L$ from Eqs.(1.29) and (1.30). Since $\delta L < 0$, we have $J(\partial K/\partial s) - K(\partial J/\partial s) > 0$ if and only if $-J(\partial^2\widetilde{p}_{ms}/\partial z_k^2) - \alpha K(\partial p_{ms}/\partial z_k) > 0$. Replacing for J and K given by Eq. (1.30) and Eq. (1.29), respectively, this inequality is equivalent to

$$\delta(\pi_{ms}^2 - \frac{s}{3}) < \delta(\pi_{ms}^2 - \frac{s}{3}) - C''(z_k)/(\frac{\partial^2\widetilde{p}_{ms}}{\partial z_k^2})$$

which simplifies to $C''(z_k)/(\partial^2\widetilde{p}_{ms}/\partial z_k^2) < 0$. This is always true. Therefore, $\partial z^*/\partial\beta$ is increasing with s. When switching costs are high, the bank reduces less its investment in liquidity risk management when its bailout expectations increase.

Online Appendix
Bailout Policies when Banks Compete with Switching Costs

For online publication only

Appendix H - Example of a liquidity shock We give an example to illustrate the simplified liquidity shock that we use in our model. We motivate the liquidity shock by a shock on the asset side (the lending portfolio) and an informational friction between borrowers and investors. We assume that borrowers are unable to repay their loans by the due date ($\tau = 1$), though being solvent. Since investors have no information about the reasons causing the borrowers' delay in repaying their loans, they still demand to be reimbursed when their investment matures, forcing the bank to sell collateral to meet their demand. As banks engage in costly collateral liquidation, borrowers need to pledge additional amounts of collateral to borrow again in the second period. Banks are then forced to restrict their supply of lending.

We formalize this example as follows. At $\tau = 0$, banks set their interest rates on loans. Each of them obtains a share of the lending market that needs to be financed. Banks lend to borrowers against a collateral: a proportion m of each loan (including interest rates) can be collected and sold by the bank at a market value which depends on market conditions at $\tau = 1$.

To finance its loans, each bank has access to its own pool of potential investors, whose size is normalized to 1. After setting their interest rates, banks raise short-term debt from their investors that matures exactly at $\tau = 1$. Each investor may claim a non-renegotiable proportion ρ_0 of the profit realized by the bank at each period and stores the proceeds of its investment outside the banking sector. If the bank is able to reimburse its investors, we assume that it is able to raise the same amount of funding at $\tau = 1$ until $\tau = 2$. If the bank is unable to reimburse its investors, we assume that the bank fails. If only one bank fails, we assume that an exogenous proportion α of its pool of investors is willing to fund the surviving bank.

Slightly before $\tau = 1$, all borrowers only reimburse a proportion ρ of their loans. The rest of the loan repayments are delayed and repaid just after $\tau = 1$, that is, after the investors' debt matures. Therefore, the proportion of loan repayments may not be sufficient to reimburse the bank's investors by the due date. In that case, the bank may be forced to sell the collateral pledged by its borrowers. If $\rho > \rho_0$, the bank makes enough profits in the first period to reimburse its investors. Hence, no liquidity risk materializes. If $\rho \leq \rho_0$, the bank is forced to sell the collateral pledged by its borrowers. In that case, we assume that the market value of one unit of collateral is l if both banks try to sell their borrowers' collateral and L if only one bank sells its borrowers' collateral, with $l < L < \rho_0/m$. As the market value of the collateral is lower than the amount promised to the investors, banks face a liquidity shock. We assume that if both banks try to sell the collateral, one of them is able to sell the collateral first (say because it first obtains the information that loan repayments will need to be delayed). Assume that one bank is the first to be informed about the shock, such that it can sell the collateral before its competitor (with equiprobability for each bank). Both banks survive if $\rho > \rho_0 - ml$, and only the first bank survives if $\rho > \rho_0 - mL$.

We assume that borrowers incur some costs of selling the collateral. This is because they need to rebuild a fixed additional amount z of collateral to continue their project with their bank and borrow again one dollar at $\tau = 1$. Therefore, depending on the severity of the shock each bank may be able to finance only λ_{fc} or λ_m new projects, with $\lambda_{fc} = 1/(1+z)$ and $\lambda_m = (1+\alpha)/(1+z)$.

Appendix I - Proof of existence and uniqueness of the equilibrium of the game
We study whether banks have incentives to deviate from the symmetric strategy and derive the conditions under which the symmetric equilibrium is unique. To reduce the number of cases considered, we will assume that first period interest rates are such that poaching arises at the equilibrium of the second period when there is no financial constraint. From Appendix A - market coverage, this is equivalent to $|r_B^1 - r_A^1| < (t-s)/2p$. In Appendix A, we showed this implies that both banks are always constrained in their insider market by their financial constraint or their market share.

Suppose that bank A charges $r_A^1 < r_B^1$ such that $x_D > 1/2$. In this case, a Necessary Deviation Condition "NDC" for an asymmetric equilibrium to exist is that bank A has more incentives than bank B to marginally lower its first period interest rate at the symmetric equilibrium, that is, we have

$$\left.\frac{\partial \pi_A}{\partial r_A^1}\right|_{r_A^1 = r_B^1} < \left.\frac{\partial \pi_B}{\partial r_B^1}\right|_{r_A^1 = r_B^1}. \tag{NDC}$$

and asymmetric market shares are possible under these conditions. In the following, we decompose between the different cases which may arise under asymmetric price, depending on its effect on the expected competition at $\tau = 2$. Since $x_D > 1/2$, for a given shock and an identical level of funding $\lambda \in \{\lambda_{fc}, \lambda_m\}$, bank B always faces either an equal or a lower financial constraint than bank A. For instance, if bank A is constrained on some insiders, then bank B is either constrained on insiders, on outsiders or none. Importantly, $x_D > 1/2$ implies that $\widehat{\lambda}_B < \widehat{\lambda}_A$ given in Appendix A (Proof of equilibrium with financial constraints at $\tau = 2$), such that bank B may be unconstrained in its outsider market, but bank A is not. Since no profitable deviation exists if the expected market structure at $\tau = 2$ is symmetric, we focus on situations where the asymmetric pricing lowers the financial constraint of bank B relative to A at $\tau = 2$.

Case 1. Only bank A is financially constrained in its insider market, i.e., $\lambda \in (1 - x_D, x_D)$. Forward-looking borrowers around x_D expect to remain with B and to have a null utility at $\tau = 2$ or to switch to B and get a utility which increase in x_D, depending on their first-period choice. Solving for the myopic and forward-looking indifferent borrowers, we have $\left.\frac{\partial \pi_A}{\partial \eta \partial r_A^1}\right|_{r_A^1 = r_B^1} > \left.\frac{\partial \pi_B}{\partial \eta \partial r_B^1}\right|_{r_A^1 = r_B^1}$ from Assumption (A5) if bank B expects to be unconstrained (i.e., $\lambda > \widehat{\lambda}_B$), and from Assumption (A6) if bank B expects to be constrained (i.e., $\lambda < \widehat{\lambda}_B$). Thus, it is sufficient to check the NDC when all borrowers are myopic, i.e. $\eta = 0$. If bank B expects to be unconstrained (i.e., $\lambda > \widehat{\lambda}_B$) in its outsider market, the NDC is equivalent to $R \leq 3t/2 - s$, which contradicts Assumption (A5). If bank B expects to be constrained (i.e., $\lambda < \widehat{\lambda}_B$) in its outsider market, the NDC is equivalent to $s \leq t(1 - \lambda)$. Given that $\lambda \in \{\lambda_{fc}, \lambda_m\}$ and $\lambda_{fc} \leq \lambda_m$ from Assumptions (A2) and (A3), this contradicts Assumption (A6) that $s > t(1 - \lambda_{fc})$.

Case 2. Both banks are only constrained by their market shares in their insider market, i.e $\lambda \geq x_D$. The only asymmetric market structure is that only bank B expects to be unconstrained in its outsider market (i.e., $\lambda \in (\widehat{\lambda}_B, \widehat{\lambda}_A)$). Forward-looking borrowers around x_D expect at $\tau = 2$ to switch to B and pay $(r_B^o)^{mu} = (p\rho + c - t(1 - x_D) - s)/2p$ or to switch to A and pay $(r_A^o)^{\overline{m}} = (R - s - t\lambda_m)/p$, depending on their first-period choice. Solving for the myopic and forward-looking indifferent borrowers, we have $\left.\frac{\partial \pi_A}{\partial \eta \partial r_A^1}\right|_{r_A^1 = r_B^1} > \left.\frac{\partial \pi_B}{\partial \eta \partial r_B^1}\right|_{r_A^1 = r_B^1}$ if $R > t(2\lambda - 1/2) + s$. Assume first this last inequality is true, such that it is sufficient to check the NDC when all borrowers are myopic, i.e. $\eta = 0$. The NDC is equivalent to $R < t(2\lambda - 1/2) + s$, which contradicts the assumption. Assume now that $R < t(2\lambda - 1/2) + s$, such that it is sufficient to check the NDC when all borrowers are forward-looking, i.e. $\eta = 1$. The NDC remains equivalent to $R < t(2\lambda - 1/2) + s$, such that it holds. However, the condition $\lambda < \widehat{\lambda}_A$ is equivalent to $R > t(2\lambda - 1) + s - (r_B^1 - r_A^1)(4 - 3\delta^b(1 - \eta))/(2(4 - 3\eta))$. Since $r_A^1 < r_B^1$, the NDC contradicts the condition for this market structure to be possible. Therefore, in this case 2, either the asymmetric market structure does not provide incentives for bank A to set lower interest rates than bank B or it is impossible. At the symmetric equilibrium, the financial constraint for both banks in their respective outsider market is binding because $\lambda < \widehat{\lambda}_B = \widehat{\lambda}_A$ from Assumption (A3).

We conclude. Under Assumptions (A1)-(A5) and $s \geq t(1 - \lambda_{fc})$, no single expected market structure which emerges only if $r_A^1 < r_B^1$ provides incentives for bank A to set lower interest rates. Therefore, no combination of expected market structure does neither, and only a symmetric equilibrium exists.

Branch closures and access to credit: do severed relationships harm borrowers?

Branch closures and access to credit: do severed relationships harm borrowers?

N. Ciet

Abstract

This paper studies whether borrowers are harmed by a closure of their bank's branch, using a combination of matching and difference-in-difference to control for endogenous variation in credit allocation. We document two main results. First, borrowers from closed branches experience an increase of around 6% in their amount of credit, two years after the closure. Second, this increase is not driven by bank supply, as borrowers are able to regain access to credit both from their previous bank and from other banks. Borrowers experience an increase in their amount of credit only when local branch density is high enough, suggesting that branch closures enable them to take advantage of local competition among branches.

Keywords: Branch, Closure, Banking Relationship, Banking Competition.
JEL Codes: G2.

1 Introduction

The decline in the number of bank branches is probably the most visible transformation of the banking industry since the Great Financial crisis (Zhang, 2020, Granja, Leuz and Rajan, 2022). As such, this phenomenon is periodically highlighted by media coverage as well as in the political debate, which conveys local concerns regarding access to cash and credit.[1] Borrowers from closed branches are among the first individuals impacted by closures, as their banking relationships with their loan officer may be severed. Therefore, they risk to be no longer identified as creditworthy (Sharpe, 1990, Rajan 1992, Von Thadden, 2004), and to lose the benefits granted to long-term credit relationships borrowers in the form of easier access to credit (e.g, Petersen and Rajan 1994) and high credit amounts[2]. In addition, the higher distance to branches after a closure may also make borrowers more opaque to lenders, because the collection of soft information on distant borrowers is more difficult (Degryse and Ongena, 2009 and Ergungor, 2010).

Despite these concerns, few articles study the effects of branch closures on credit access. It remains unclear to what extent borrowers from closed branches indeed lose their relationship benefits, and how changes in the distance to branches affect the credit access of established borrowers. A key reason for this scarcity of studies is the need of detailed data at the branch borrowers level. This lack of different studies is also unfortunate for comparison purposes, because the effect of branch closures is likely to vary among countries, and because the relative benefits of relationship over transactional lending depends on macroeconomic conditions (Bolton et al., 2016).

In short, this article focuses on the effect of branch closures on the intensive credit margin of corporate borrowers in France, and it explores potential mecanisms driving this effect. To undertake this study, we take advantage of the *Banque de France* credit registry, together with a directory of branches in France. We find that, during our period of interest, borrowers from closed branch experience a relative increase (more precisely, a lower decrease) in their credit amount, with respect to similar other borrowers. This effect targets relatively safe borrowers, who already dispose of undrawn credit amounts. Therefore, the increase in credit amount does not represent a lifting of the financial constraints imposed by the closed branch, but it benefits favored firms. We document that the effect of not driven by supply-side effects from the bank of the closed branch, but it is split among the different banks engaged in a relationship with borrowers. Finally, we show that the effect depends on local credit competition. The increase in credit exists for both rural and urban borrowers, but it hinges on a sufficient density of local branches.

We get access to information on branch closures and on their localisation from the directory of branches issued by the *Banque de France*. We focus on the period between January 2015 and March 2020, which represent a period of relative credit expansion for corporate borrowers and stability for the French banking sector. We match this information with the French credit registry. A credit registry offers three main advantages: first,

[1] Focusing on Europe and our period of study, see for instance Brignall (2019), Devreux (2019), or Lederer (2020) for examples of media coverage. Media attention of branch closures gained traction amid transformation of banking usages during the covid pandemic. On the regulatory side, the Financial Conduct Authority (2018) in the UK and the Australian Treasury (2022) especially work on identifying "last branch in town" situations, and assess banks' efforts to promote continuation of banking access.

[2] See Degryse, Kim and Ongena (2009, Table 4.10C) for a survey of this literature.

we observe, at the firm-branch level, all French firms with total credit lines over 25k€, which enables us to identify the impacted borrowers, and to control for endogeneous threats to identification at the firm level. Second, the credit registry collects monthly credit information at the branch-firm level. This level of detail enables us to track the dynamic effects of closure on credit change, and therefore to isolate the effect of closure from the trends in local economic conditions. Third, for each borrower, we observe detailed informations regarding the type(s) of credit they own, as well as individual information.[3] This enables us to observe the maturity of outstanding credit of each borrower, and thus to control for pre-existing differences in credit usage among borrowers.

Identifying the effect of branch closures in challenging for two main reasons. First, branch closures may be endogenous to borrowers' creditworthiness. To control for this potential endogeneity of the borrowers' characteristics with respect to the decision to close a branch, we take advantage of the credit registry to use a combination of matching and differences-in-differences. By requiring an exact matching on firms' characteristics, bank, and credit relationship variables, we aim at getting closer to the needed counterfactual of firms experiencing closures. Second, the timing of branch closures is staggered (i.e., occur at different periods), such that simple differences-in-differences will be biaised (e.g., Borusyak and Jaravel, 2017).[4] Following recent advances in the estimation of staggered events, we follow the estimation procedure of Cengiz et al. (2019). We match treated with non-treated borrowers a quarter before branch closure, in order to form cohort-specific datasets for every treated borrower. We then stack these cohort-specific datasets, and we estimate the effect of the branch closure within each matched cohort.

The results are as follows. First, we observe that borrowers from a closed branch experience a relative increase in their loan amounts with respect to similar non-treated firms. Their amount of credit increases steadily with respect to these other borrowers for two years after the date of their branch closure, at which point they hold on average 6% more credit amount then before closure. This effect is robust to variations within our matched sample and to additional fixed effects and control variables, and it is homogeneous with respect to borrowers' size and to the number of their banking relationships. As opposed to other borrowers, riskier borrowers do not undergo a similar increase in their loan amount following branch closure, but they neither face a tightening of their financial constraints. Borrowers drawn steady amounts of credit, but they increase the volume of their overall available credit. Therefore, this relative increase in credit does not represent a lifting of stronger credit constraints before the closure, and it targets most favored borrowers.

We then investigate whether this positive effect of branch closure stems from a shock

[3] Similar to most credit registries, the French credit rgistry does not include information on average interest rates or collateral requirements.

[4] Two-way fixed effects estimations are unbiaised in the treatment is homogeneous across individuals and over time, which is very unlikely in pratice.

on the branch hosting borrowers' outstanding credit from the closed branch (the receiving branch, hereafter), or from other changes in the credit conditions after the branch closures. Specifically, we disentangle two possible mechanisms. A first explanation is that receiving branches are more efficient in providing financial services to borrowers than closed branches, such that borrowers' credit increase. In practice, branch closures generate economies of scale for banking groups, which enable receiving branches to deliver more specific services to borrowers, from loan officers dedicated to corporate customers to tailored consulting services and financial tools. Consolidation of branches may also improve credit supply to previously isolated areas (for evidences in Spain, see Alamá et al., 2015 and Martin-Oliver, 2019). We call this explanation the *expertise effect* . A second explanation is that the disruption in existing banking relationships enables borrowers to renegotiate their credit conditions with the receiving branch, and it renders switching to rival branches more frequent. We call this change in the credit environment due to branch closure the *renegotiation effect*.

We provide three pieces of evidence which suggest that the relative increase in credit following branch closure stems from a change in borrowers' demand or from general credit conditions after the closure (i.e., *renegotiation effect*) and not from a supply shock from the bank which planned the closure (i.e., *expertise effect*).

First, we study the effect of specific branch closures that we excluded until then, because they follow the merger and absorption of their banking groups. Possible efficiency effects are likely to be exacerbated for these branch closures, as treated borrowers are transferred to a branch of the new banking group instead of keeping their previous branch relationship unchanged by the merger. At the bank level, we provide evidence that the merger generates changes in risk assessment, which may indicate expertise gains from the merger. However, we find no effect of these branch closure on the credit amount of treated borrowers, with respect to similar borrowers from the merged bank.

Second, following Khwaja and Mian (2008), we show that, in the direct aftermath of the transfer, receiving branches update borrowers' credit which was previously reported as drawn if it remains undrawn. However, they do not increase their total supply of credit with respect to the borrowers' other banks.

Third, we show that only branch closures from banks with little local branch presence, or with high presence of competing branches, generate an increase in their borrowers' credit amount. This heterogeneity holds even if we focus on borrowers from rural areas. This role of local competition suggests that borrowers seize the opportunity of their branch closures to renegotiate existing credit conditions with their bank or to engage in new credit relationships.

We contribute to the nascent literature addressing the consequences of branch closures on credit amounts.[5] Using US chart-level data, Nguyen (2019) shows that branch closures lead to a durable 13% decrease in the amount of new loans to small businesses. To tackle the endogeneity problem, Nguyen focuses on closures induced by consolidations after a bank merger, and she instruments branch closures by the variations in the exposure to a consolidation at the Census track level. Our analysis differ on many aspects. First, we do not consider branch closures after bank mergers in our main setting, where it may be difficult to disentangle the effect of branch closure from the effect of a merger. Also, when we turn to merger-induced branch closures, our data enables us to use similar borrowers from the merged bank as a control group. Second, we focus on the effect of branch closures on borrowers from the closed branch. Finally, we consider branches closures under different local conditions, while merger-induced branch closures occur mostly in areas with dense branch networks. Using credit registry data from Italy and Portugal, Garri (2019) and Bonfim and Ongena (2021) analyze the effects of branch closures where the branch closed was the only local branch from its banking group[6]. Using similar estimation methods as us, they find no effect of branch closures on the credit amounts of borrowers in Italy and Portugal. We provide additional evidence that branch closures have no effect on credit availability in areas with a lower number of branches, and we also show that the presence of competing branches in more important than the number of local branches of the bank which initiated the closure. Finally, our dataset follow closely Duquerroy and al. (2022), who use French branch closures as a shock to study the importance of branch sector specialization. Focusing on the period 2010-2017 and SMEs with multiple relationships, they find no evidence that branch closures lead to changes in total credit amounts, and negative supply-side effects before the closure, starting two years before the closure date. Unlike in their paper, we fully take into account the staggered nature of branch closures in France to estimate their effect on total credit access, and we include a larger set of firms and branches.[7]. Also, unlike all articles mentionned before, we focus on the period after the final phase of deployment of Quantitative Easing programs by the ECB (in particular, the Asset Purchase Program in 2015 and the Corporate Sector Purchase Program in 2016), when credit conditions improved (Albertazzi, Becker and Boucinha, 2018, Betz and De Santis, 2019, and Funk, 2019).

Our article also relates to the literature on the local effects of branch mergers, since

[5]For a study on the effect of branch closures on the economic activity of Spanish SMEs and Swedish firm formation, see Martin-Oliver et al. (2021) and Ho and Berggren, 2020. Other studies on shocks at the branch level include Drexler and Schoar (2014) on loan officer turnover in Chile, and Xu, Sanders, Xiao and Li (2020) on the effect of a forced reallocation between borrowers and branches following a legal change in China.

[6]More precisely, in Bonfim and Ongena (2021), the closest remaining branch of the same bank must be more than 5 kilometers away from the borrower. In Garri (2019), the closest remaining branch of the same bank must be in another municipality.

[7]They focus on SMEs with multiple banking relationships, while we include sole and micro entrepreneurs, midcap firms, and single-relationship firms. Also, they focus on mainland France, and on branch closures from the largest banks.

in most OECD countries branch closures are mostly driven by consolidation (Keil and Ongena, 2020). Recent evidence on the effect of merger on credit availability is mixed (see DeYoung et al., 2009, for a survey), but mergers are find to generate important reassessment of credit risk, based on hard information usage (Di Patti and Gobbi, 2007, Panetta et al., 2009). We complement the literature on bank mergers by isolating the consequences of branch closures on credit amounts from bank-level effects. In line with existing evidence, we provide additional evidence that bidder banks reassess the portfolio of merged banks. We complement on this effect by providing some evidence that the effect of the merger is homogeneous across closed and non-closed branches from the merged bank. In particular, we observe no specific credit reassessment on the assets transferred from a closed branch, which suggests that the credit reassessement is performed at the banking group level.

Finally, we contribute to the empirical literature which study the role of geographical distance on credit rationing, with contrasting results. Degryse and Ongena (2005) and Agarwal and Hauswald (2010) find that closer banking relationships benefit from easier credit access, while Petersen and Rajan (2005) or Carling and Lundberg (2005) suggest that technological changes mitigate the importance of local soft information. As opposed to these articles, we focus on the consequences of changes in the distance between lender and borrower on credit availability. We highlight that local competition, proxied by branch presence of the bank closing branches and by competing branches, shapes the ability of borrowers to take advantage of their branch closure to increase their available credit. Borrowers may benefit from the increasing distance with their lender, but only if local branch networks remain dense enough.

The remainder of the paper is organized as follows. In Section 2, we describe our datasets, and we provide contextual references on branch closures in France, focusing on branches which grant credit to corporate borrowers. In Section 3, we outline our empirical methodology. In Section 4, we present our main results on the effect of branch closures on firms' amount of credit. In Section 5, we investigate possible explanations for our result, focusing on the respective roles of the receiving branch expertise and competition for borrowers from closed branches. We also discuss the external validity of our results, and its relationship with the existing literature. Section 6 concludes.

2 Data and descriptive statistics

We focus on branch closures occurring during the period starting in January 2015 until March 2020, before credit conditions drastically changed following massive government intervention on credit markets. In order to check for firms' credit conditions before closures for all our our period of analysis, we also keep the seven quarters before closure, such that our dataset include quarters from July 2013 onward[8].

The main dataset we use is the *Banque de France* credit registry (named the *Service Central des Risques)*, which reports each month at the firm-branch level all the credit volumes of firms with a total exposure to the parent bank exceeding 25k€in France.[9] Credit exposures are broken down by maturity (short term or long term), availability (drawn or undrawn), and usage (commercial credit, factoring, leasing...). We aggregate the data at the firm-bank-postal code level.[10] The dataset also provides information on the sector of activity of firms, divided initially between 38 categories. Finally, the credit registry reports additional measures on risk, estimated by the *Banque de France* for firms with annual turnover over 750k€.

The history of branches in France is provided by the *Fichier des Etablissements et Fichiers Agrées.* This directory lists all branches in France and Monaco from banking groups which have a division in France, at the notable exception of French post offices and a small cooperative bank.[11] For each branch, it reports its banking group, postal code, day of opening and if relevant its date of closure, as well as its ability to emit and receive payments. It also reports whether the branch has been closed or transferred to another branch. This directory is actualized on a daily basis, and we access to the directory at two extraction dates (July 2018 and May 2021). At each date, the directory keeps all information on closed branches for a minimum of 14 months, or as long as the banking group is active, if customers from the closed branch benefit from an invariant banking account facility.[12]

2.1 Data cleaning and definitions

Data cleaning

The credit registry contains some information which is irrelevant to our study, which focuses on corporate borrowers. We exclude non-French firms, public administrations, as well as (most) real-estate firms.[13] We do not consider large corporate firms, but we include

[8]In July 2013, the French government adopted a major reform regarding the separation of banking activities.

[9]All data used from the Banque de France includes French Overseas Departments and Territories.

[10]Some branches might also use secondary identifications to store activities which do not need to emit or receive payments from other financial entities. In practice, around 0.1% of firms have credit relationships with different branches of the same town and bank.

[11]These two banks only report credit at the national level. In December 2016, they account for less than 1% of outstanding loans to SMEs (see Duquerroy et al, 2022).

[12]In France, this facility is provided by all large private banks, but not all cooperative banks.

[13]We drop firms defined as Societes Civiles Immobilères, which are non-commercial entites representing a common form of management of real estate assets for groups of individuals or companies.

micro-enterprises.[14] We also drop firms with missing size classification.

The directory of French branches is maintained by the Banque de France to identify and authorize interbank payments. To ease the line closing process, we remark that the closure of the branch identification may slightly lag behind the closure date, as reported on the French Company Register. Multiple cross-checking with news reports suggest that this date often exceeds the effective date of branch closure. We tackle this issue by defining the date of closure as the maximum[15] date between the closure date reported in the branch registry and the date of transfer of most borrowers from a branch in the credit registry.[16] This strategy also enables us to focus on the date of closure as it is experienced by corporate borrowers, as they may not benefit from a leniency period granted to individual borrowers and depositors. Banks may decide to change some branches' identification for other reasons than closure. As a consequence, we conservatively interpret an exit from the branch registry to be different from a branch closure if the recipient branch identification is less than one month old at the time of exit.

Definitions

Definition of branch closure & date of closure We include as either closures or branch ID changes all events defined as such within the directory database (FEGA), as well as branches which disappear between our two directory extracts (see Table 1). We consider that the branch is closed if the receiving branch existed before the transfer, or if it is located in another town. Therefore, we avoid considering as closures redenominations of single branches for I.T reasons or following a merger. Finally, at some point during our analysis, we will also consider 34 branches, absent from the directory database because of their foreign status, to be closed when they stopped registering any borrower in the credit registry.

Definition of treated and non-treated borrowers We define firms affected by a branch closure ("treated firms", hereafter) which are in relationship with a closed branch in the year before closure.[17] If a borrower faces multiple closures, we select the first date

[14]From the French LME Act of 2008, SMEs represent firms with a turnover between 2M€and 50M€(or with total assets between 2M€and 243 M€), and which employ 11 to 250 workers.

[15]Many banks in France now provide their consumers with invariant ID advantage, such that, in a few cases, branches still report borrowers beyond their closure date, as defined in the credit registry.

[16]From the credit registry, we consider the last wave of transfers in the past 18 months before the date of closure as reported in the branch registry, where at least 50% of borrowers present in the previous month are transferred from branches with over 10 borrowers.

[17]We assume that the relationship is maintained between the branch and the firm during non-reporting periods, as long as credit is reported before and after this time span.

among the different closure dates.[18] We discard borrowers who drop from the credit registry in the three months after closure. On the contrary, non-treated borrowers include all firms which neither experienced a branch closure before and during our period of interest.

2.2 Branch closures in France

Compared to most developed countries, banks in France decrease the size of their branches' networks at a slower pace than in comparable countries (see Figure 1a). This slow transformation is all the more surprising as France has one the most dense branch network in the world (see Figure 1b). This dense coverage of the French territory implies that France, unlike countries with a less dense network, is less endangered by the risk of banking deserts. Indeed, a majority of branch closures occur during our period in large cities. In rural areas, branch closures are located in previously over-branched areas (e.g., Center and South-West of France), while less equipped regions (along the Atlantic ocean) experience branch openings over the period (see Figure 2). On the contrary, other regions (North East) experience a stark decline in the number of branches over the period, which suggest the existence of specific reorganizations from regional banks.

This slow decline in the number of closures in France relates to the presence of large networks of cooperative institutions, which face stronger incentives to maintain local branches. During our period of analysis, most branch closures follow internal reorganizations, as there had been no large bank merger. In parallel to the decline in the number of branches, banks also resort to tighter opening hours, or other forms of internal reorganizations, to reduce the cost of their branch networks.

Between 2015 Q1 and 2020 Q1, we observe a total of 35,049 branches in France. Some of these branches only serve individual borrowers or take deposits. Focusing on branches which grant credit to firms, 2,389 branches closed between 2015 and 2020, i.e around 10% of 24,545 branches active during our period. The *net* decline in the number of branches, on the contrary, is limited at 5% during the period, with 1.051 opened branches. 53% of closures occur in urban areas, whereas 42% of all branches are located in cities.

81,559 borrowers experienced (at least) one branch closure during the period. They represent 3% of the population of corporate borrowers. As a consequence, closing branches are smaller than other branches, more urban, and less likely to be specialized in corporate lending. In the next subsection, we provide more details on the corporate portfolio of closed branches when describing our dataset.

[18]Mor precisely, we first keep, at the firm-bank level, the last branch closure date, in order to drop potential early termination of payment lines before the effective closure of the physical branch. We then select, for each borrower, the first of the remaining closure dates.

2.3 Descriptive statistics

At the branch level

In Table 2a, we provide a detailed picture on closed branches between January 2015 and March 2020. This serves two purposes. From a general perspective, this documents a simple portrait of closed branches and borrowers which is, to the best of our knowledge, missing from the literature, with the exception of Bonfim and Ongena (2021) on Portugal. Second, it highlights the nature of the selection problem at the branch closures and firm level.

Closed branches host less corporate activities than branches from the control firms and receiving branches. They host half as many borrowing firms than other branches, and they hold than 4 times less corporate credit.[19] Therefore, closed branches has less borrowers, but they receive more credit than another firms. Also, closed branches serves different credit usages, as the proportion of undrawn credit lines is 2.5 lower than other branches. This either imply that closed branches are smaller, or that they are not specialized in corporate lending.

As we already mentioned, closed branches are more urban, but they tend to be located in cities with a relatively low number of branches.[20] On average, there are only 38 other branches, while (more rural) other branches are located in the same town as 33 branches on average. The banking group of closed branches owns on average 13.2% of branches in the town of closed branches, which is just slightly higher than the average local market share elsewhere of 12.1%. Finally, they face similar competition environments, which we measure by the Herfindahl-Hirschman Index. As a consequence, banking groups do not seem to target closures in locations where they are over represented, or which are crowded in general. This suggests that other determinants may influence the closure decision, from local economic conditions to underperformance of a branch portfolio.

The share of short and long term maturities over total credit is the same for closed and non-closed branches, such that closed branches developed a similar relationship intensity with their borrowers as other branches before closing. This is confirmed by few differences in the duration of branch-firm relationships, as the average duration of a firm-branch relationship is only 8 months smaller for closed branches than other branches, not correcting for the disruption caused by the closure itself.

Finally, we also report descriptive statistics on receiving branches (i.e, branches which

[19] We include short and long term credit, undrawn credit lines, overdrafts, export credits, leasing and factoring.

[20] We define cities as towns with over 50.000 inhabitants in 2019, and all towns adjacent to cities over 100.000 inhabitants.

take over firms' outstanding credit following closure). [21] Unlike closed branches, the receiving branches have the same size and credit composition as other branches. They are even more often located in urban areas than closed branches, and, as a consequence, in more competitive local markets than other branches and closed branches.

At the firm level

At the quarterly firm-level, Table 2b displays the characteristics of treated and of other firms, focusing again on corporate borrowers. On average, treated firms own 1246k€of outstanding credit, with half of the firms borrowing less than 150k€. For comparison, firms which are non-affected by branch closures only own 593 k€of credit on average, with a median of 93k€. This discrepancy between treated and non-treated firms is very likely to come from clear selection into treatment: by definition, firms are more likely to face a closure if they hold multiple banking relationships. Firms with multiple relationships tend to be bigger, to borrow more and to have more stable credit access (Houston and James, 1996, Ongena and Smith, 2000, Detragiache et al., 2000). We observe that treated firms hold almost 2 banking relationships on average, while other firms only hold 1.36.

In the following section, we explain in more details our matching procedure, which include both the number of banking relationships and the volume of credit.

3 Identification strategy and empirical framework

A bank's decision to close a branch remains *a priori* endogenous to local economic conditions and to branch profitability. Therefore, even if closed branches manage a low proportion of corporate assets, firms' credit access may be endogenous to their branch closures.

A second, and possibly related issue relates to attrition of borrowers following closure. Documented as an important effect of branch closures in Italy (Garri, 2019), attrition may generate a positive bias on the estimation of changes in credit amounts, as surviving firms may raise credit more easily, and deplete their outstanding amounts more slowly by borrowing with longer maturities.

Even if branch closures were completely randomly assigned, treated borrowers may still differ based on their characteristics, with respect to other borrowers. Indeed, borrowers with multiple relationships are by definition more likely to experience a branch closure. Depending on whether borrowers with multiple banking relationships are riskier (Detragiache,

[21] We do not always have data on the identity of receiving branches, such that we only use this category for illustrative purposes. For each closed branch, we define a branch to be its takeover if it is the branch which receives the most new (i.e., without past relationships with this branch) borrowers from the closed branch, the month after borrowers are transferred from the closed branch.

Garella and Guiso, 2000) or safer (Degryse, Masschelein, and Mitchell, 2010), this sample selection of treated borrowers will mitigate or exacerbate the effect of branch closures.

Finally, in France, branch closures are typically staggered, and most of them cannot be attributed to specific shocks at the bank level. We may expect the effects of branch closure to be time-varying for at least two reasons. First, the effects can be delayed for a given borrower until it needs to renew its credit operations. Second, inertia in credit volumes of a given borrower imply that the effect of closure may be delayed. The staggered nature of branches closures, together with the possibility that the effect of closures varies over time or across borrowers, implies that simple difference-in-differences are inappropriate (see, among others, Borusyak and Jaravel, 2017 and Goodman-Bacon, 2021).

3.1 Identification strategy

To identify the effect of closure on firms' access to credit, we follow a two-step procedure: we first match treated and non-treated firms based on some observable characteristics defined in Table 3a, and we estimate the effect of closure on treated borrowers using a difference-in-difference model, with matched non-treated borrowers being a control group. To take into account the staggered nature of branch closures, we employ a stacked differences-in-differences approach, as proposed by Cengiz et al. (2019). In practice, four months before a branch closure, we select matching treated and control firms, and we observe them between 5 quarters before and two years after closure. We then "stack" all these sub-experiments, before estimating the model defined below.[22]

3.2 The matching procedure

To control for observable differences between treated and either never-treated or not-yet treated firms, we attempt to match, three months before the date of branch closure, each firm which face a closure with the two untreated borrowers along their constant characteristics, their credit activity and their branch location (see Tables 3a and 3b for the definition of each variable using for matching). We first impose exact matching on three firms' constant characteristics, which are the sector of activity (with 10 categories), firms' risk (with 6 levels of risk) and the firms' group structure (holding, subsidiary, branch, or none).

After firms have been filtered based on their constant characteristics, we further require an exact matching on some credit and local characteristics, which we extract three months before the branch closure takes place (the "matching date" hereafter). First, control and treated borrowers must both either have a single or multiple banking relationships. In

[22] Given that we define an event at the firm level with a small number of control firms, we do not estimate our model "event-by-event" (Online Appendix D, Eq.(D.6) in Cenzig et al., 2019), but stack all events to calculate an average effect across events (Online Appendix D, Eq.(D.7) in Cenzig et al., 2019).

addition, one of these relationships must be with the same bank, whether or not it is the bank which closed a branch. By matching firms based on their identity of their bank(s), we follow Ioannidou and Ongena (2015) and Bonfim and Ongena (2021), to partially control for supply-side effects at the banking group level, which may correlate with the group decision to close branches.[23] We also match firms based on their branches' urbanicity.[24] Therefore, we aim to compare firms with similar branching accessibility.

We also match borrowers, depending on whether they only hold long-term credit at the matching date. Regarding the credit characteristics of borrowers, we finally match together borrowers based on a simple credit history criteria. We distinguish four groups: firms which increased and decrease their credit during the year before the matching date, borrowers who only had non-credit (i.e., financial commitment to third parties) a year before closure, and borrowers who entered in a banking relationship during the year before the matching date. By using these very aggregate categories, we aim to proxy for differences in the maturity of firms' liability structures, measure the intensity of the relationship between the borrower and its branch, and control for late entry in our estimation period.

We tackle the potential issues related to the attrition of borrowers by imposing matched borrowers to exit within the same year if they exit our dataset in the 2 years after closure date.

Finally, we select of each treated borrower, within each group defined above, the two non-treated borrowers with the closest total amount of credit within the same town. If there are less than two control firms of the same town as the treated borrower, we select remaining control firms by gradually widening the geographical pool of candidates at the county level, the state level, and finally at the whole country level if needed.[25] We do not match exactly on geographical location in order to avoid selecting mostly branches and borrowers from populated areas.

By selecting control borrowers based on our main variable of interest (the credit amount) at the very end of our exact matching procedure, we employ a simple criteria to distinguish among control candidates, without imposing any statistical equality with treated borrowers. As will become apparent when we will compare our control and treated population, we thus do not (statistically) match on pre-treatment outcomes, therefore avoiding regression to the mean problem (e.g., Daw and Hartfield, 2018) or other forms of biais (Chabé-Ferret, 2017). This follows from the small number of remaining candidates

[23]In the context of branh closures, cost savings on branching infrastructure could relax the financial constraints on banks immediately, thereby enabling them to provide more credit to all their borrowers.

[24]Therefore, we match at the firm-branch level, and not at the firm level. If firms hold relationships with branches of different geographical characteristics, we allow the firm to belong both to a rural or an urban matching category.

[25]French *départment* (country) and *régions* (state). They are 96 *départment* and 18 *régions* in France main land (including Corsica). We group together overseas *d épartments.* On average, a French *région* area is 1/6 the size of a US State.

after our exact matching procedure.[26] As a robustness check, we will also consider credit amount as a matching variable, and we will sligthly modify our matching procedure accordingly.

By using borrowers' characteristics three months before closure, we control for (local) common changes in economic and credit conditions. The choice of this specific benchmark date is motivated by the necessity to avoid potential mismatching concerns, if branch closures generate announcement effects on borrowers' credit decisions or on the incentives of loan officers to accept credit requests. Indeed, numerous anecdotal evidences suggest that most branch closures decisions become public one or two months before the effective closure, with cooperative banks having in general longer annoucement periods than private banks.[27]

Matching without replacement, we obtain a balanced panel of 29.858 borrowers which face closure and 59.716 control borrowers.[28] They faced a closure from 1.414 branches. Therefore, we are able to match 61% of the 48.663 treated corporate borrowers present in the credit registry three months before closure, and we represent almost all of 1.428 branches with these firms. Given that we implement an exact matching on most of our matching variables, we report in the third column of Table 3c t-test statistics of treated and control groups at the quarter before closure, for a sample of variables which we do not (exactly) matched on. Treated borrowers engage in slightly more relationships, as we assume, in line wth the existing literature, that the relevent heterogeneity among borrowers is whether they hold multiple banking relationships. Because our matching procedure focuses on credit composition, treated firms also appear to raise higher amounts of credit than control firms. As a robustness check, we will also report our main result when borrowers hold similar amounts of each credit type, and we report t-test in this case in column 6.

[26]Excluding the date, each bank-firm relationship falls inside one of the 38,6M different matching categories possible (see table 3a).

[27]libercourt.fr/fermeture-annoncee-de-la-caisse-depargne-la-municipalite-sengage-aux-cotes-des-libercourtois

94.citoyens.com/2021/champigny-sur-marne-la-derniere-agence-bancaire-du-bois-labbe-sen-va,10-03-2021.htmlhttps://www.lefigaro.fr/conso/en-charente-un-maire-de-24-ans-dit-non-a-la-fermeture-de-la-derniere-agence-bancaire-de-son-centre-ville-20201003

lefigaro.fr/conso/en-charente-un-maire-de-24-ans-dit-non-a-la-fermeture-de-la-derniere-agence-bancaire-de-son-centre-ville-20201003

moneyvox.fr/banque/actualites/84496/exclusif-ces-650-villes-qui-ont-perdu-toutes-leurs-banques-en-10-ans

[28]In our sample, 5% of treated borrowers, i.e 4.250 firms, have less than 2 controls because of no-replacement of matching firms in our control group.

3.3 The model

We employ a stacked differences-in-differences approach, as proposed by Cengiz et al. (2019). We group together a matched treated firm and its two control firms, and we trim our data to keep only observations between 5 quarters before and two years after closure, with date 0 representing the quarter during which the closure occurs. We then stack all these sub-experiments ("cohorts"), and we estimate the following model

$$\log(1 + Y_{ic\tau}) = \Sigma_{\tau \in T \setminus \{-1\}} \beta_\tau C_{i\tau} + \eta_i + \lambda_{c\tau} + u_{ic\tau} \tag{2.1}$$

where Y_{ict} is the credit of firm i, belonging to matched cohort c, in quarter τ, $C_{i\tau}$ a dummy variable equal to 1 for firms experiencing a branch closure at quarter τ, with $T = (-5, .., 8)$ denoting the number of quarters before or after closure.[29] Similar to a two-way difference-in-difference, our main coefficients of interest β_τ in Eq.(2.1) represent the difference in credit granted between treated and control borrowers within each matched cohort at each period τ, with respect to their difference a quarter before closure. Note that, as opposed to Cengiz et al. (2019), we do not need to interact cohort- fixed effects with individual fixed effects or control variables, as we exclude all treated borrowers during the period from being potential controls. Therefore, we need not to worry about same borrowers being both "not-yet-treated' control borrowers and treated borrowers, depending on the cohort considered. The time fixed effects $\lambda_{c\tau}$ in Eq.(2.1) control for common time-trends in the variations of credit within each cohort.[30]

To shed light on the magnitude of the effect of branch closure, we also estimate a less flexible version of the difference-in-difference in Eq.(2.1), using a two-way-fixed effects model:

$$\log(1 + Y_{ic\tau}) = \beta_{post} PostC_{i\tau} + \gamma X'_{i\tau} + \eta_i + \lambda_{c\tau} + u_{ic\tau} \tag{2.2}$$

where $PostC_{i\tau} = 1$ if borrower i already experienced a closure at quarter τ. Here, the coefficient β_{post} represents the average change in credit amount after closure. With respect to previous analysis, it represents a weighted average of the difference in lending. Branch control variables $X'_{i\tau}$ include Herfindahl-Hirschman index at the town level, the number of corporate borrowers in the branch, the number of branches from the same bank in town, and the number of French states (*régions*) where the bank group is present. As the estimation of Eq.(2.2) is at the firm level, for firms with multiple relationships, we keep the average characteristic among firms' relationships, weighted by the proportion of firm's credit hosted by each branch. Also, to partially avoid a "bad control" issue (Angrist and Pischke, 2008), we set branch control variables at their pre-closure value.[31] Finally,

[29] In all regressions, errors are clustered at the firm level.

[30] Alternatively, we also estimate the model in Eq.(2.1) with common time-trends λ_τ across all different matched groups around the quarter of closure $\tau = 0$.

[31] We therefore may exclude a small proportion of control or treated borrowers who get credit from a newly opened branch after the benchmark date when we control for branch charateristics.

in some specifications, we also include bank fixed effects, which is defined in the firm-level regression of Eq.(2.2) as the banking group of the main branch of the firm, i.e., the branch which hold the majority of the firm's short-term credit.[32]

4 Results

4.1 Dynamic effects

In Figure 3, we plot the results of the leads-and-lags estimation of Eq.(2.1), together with the confidence intervals of each coefficient. Each point represents, within each matched cohort at quarter τ, the average difference (in %) in credit volumes between treated and non-treated borrowers, with respect to their difference one quarter before branch closure.

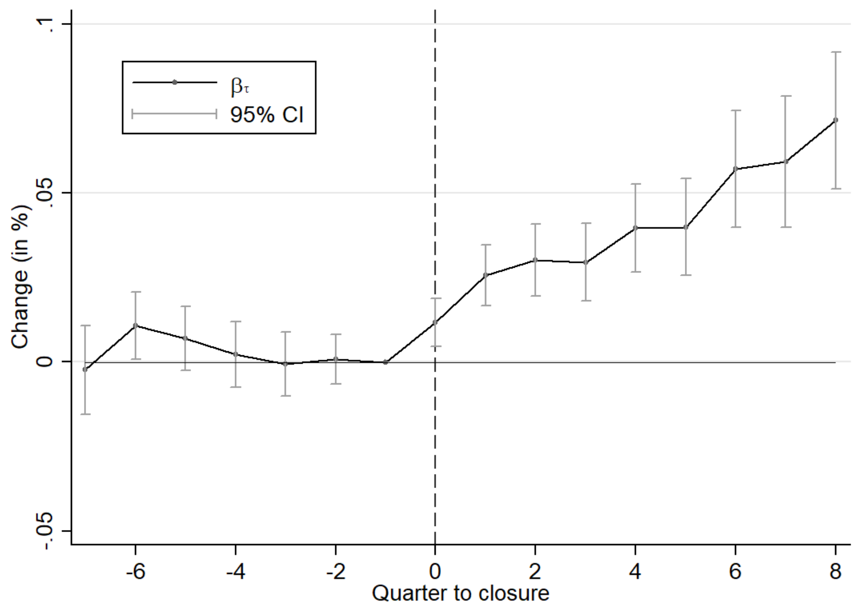


Figure 2.1: Figure 3 - Estimation of Eq.(1)

Credit volumes are higher for treated borrowers for every quarter after their branch was closed. Given that credit amounts decrease for both types of borrowers in our matched sample, Figure 3 implies that credit decreases at a lower pace for treated borrowers. This slower decrease holds for almost every quarter after the closure. The effect is especially strong in the first two quarters following closure, where the difference in the credit volume increases by 3%, and it continues to hold in the following quarters steadily. After seven and eight quarters, the differences in the credit volumes of treated borrowers reach, respectively,

[32]If the firm does not have short-term credit, we use, if any, the total amount of credit drawn at the firm-branch level, and the total amount of credit otherwise.

6% and 7%, within cohorts which have not already terminated their credit relationships at that time.

Both effects are incompatible with potential announcement effects during the quarter of closure, where a borrower would increase its credit before losing access to its local branch. Importantly for identification purposes, Figure 3 also shows the validity of the parallel trend assumption in the six quarters before the quarter used as a benchmark. Thus, it contradicts the possibility that our result is driven by different credit dynamics between treated and control firms before the branch closure.

4.2 Average and total effects

Table 4 shows our estimate of the average effect of branch closures on firms' credit, as specified in Eq.(2.2). As a benchmark, in columns (1)-(3) we first estimate a standard two-way-fixed effects model, where we only take into account for aggregate quarter fixed effects to control for aggregate variations in credit reimbursements and renewals. In columns (4)-(6), we turn to our main estimation of Eq.(2.2), which consider differences in credit amounts within cohorts by including cohort-quarter fixed effects.

In both specifications, we estimate that branch closures lead to a significative increase in credit amounts of around 3% during the two years after closure, with respect to control borrowers. In columns (2) and (3), we include branch controls defined above. Thereby, we aim to control further for potential selections bias of borrowers from closed branches, which may drive our result. For instance, smaller, more urban branches, which represent the typical closed branch, may deliver easier ATM and face-to-face withdrawal facilities than other branches, thus hosting firms with more intense banking relationships than others (Dick, 2003). Even if we observe no specificity in the number of local bank branches, borrowers may also benefit from easier credit access if closures occur in towns where banks can charge higher mark-ups (Temesvary, 2015). Taking into account branch controls, our estimate slightly increases. This highlights that, given that closed branches tend to be smaller and more urban, borrowers from closed branches sustain a higher amount of credit than borrowers from similar branches.

Finally, in columns (3) and (6), we introduce additional period-main bank fixed effects at the cohort level. Therefore, we exclude from our estimation firms with multiple banking relationships, if they have not been matched based on a similar main bank, but only based on a similar banking relationship in general. This strategy enables us first to control for the local credit variations on the bank level which matter the most for firms. Second, it alleviates any concern that our result could be driven by an over-representation of firms with multiple relationships in our matched sample, as they are more likely to find a match with a same bank relationship, and a priori more skilled to maintain the credit access following a branch closure. Following this restriction, our estimate of the effect of branch closure actually increases slightly to 3.8% or 4.7%, suggesting that our result is not determined by an over-representation of firms with multiple banking relationships.

Because of attrition, the average effect of closure β_{post} in Eq.(2.2) understates the total effect in the two years after closure, as only half of the cohorts keep their credit lines until two years after the closure. To estimate long-term effects of branch closures, we finally reestimate Eq.(2.2), keeping only firms' credit amounts during our benchmark quarter and two years after the closure. This long-term estimation also ensures that our standard errors are robust to auto-correlation (Bertrand, Duflo, and Mullainathan 2004). In Table 5, we present estimations results with (columns (1) and (3)) and without branch controls (columns (2) and (4)). Because a necessary condition for our cohorts to be included in these long-term estimations is that at least the treated firm and one control firm still holds a credit relationship two years after the closure, we may face few control firms and a loss in the precision of the estimation. Alternatively, if we focus on the cohorts where both control firms remain present, we may introduce a bias in the estimation.[33] In light of this trade-off, we present estimation results both with and without constraining the two control firms to be present in the credit registry two years after the matching date.

The results are presented in Table 5. In columns (1) and (2), we show that branch closures increase significantly the credit amount of borrowers by 6% two years after the closure, when we include all possible cohort sizes. Focusing on cohorts where both control firms remain until this date, results in column (3) and (4) are of similar magnitude, with branch closure increasing the credit amount of borrowers between 5% and 6%, depending on the presence of pre-closure branch control variables. In absolute values, this represents a 126k€credit difference from a mean credit amount of 1.8M€before closure for treated borrowers included in this estimation.[34]

4.3 Decomposition by credit type and credit reallocation

So far, it remains unclear whether borrowers from closed branches sustain higher credit amounts then other borrowers after their branch closure because their pre-existing financial constraints ease, or because branch closures lead to an intensification of credit usage by firms. To distinguish between the two interpretations, we decompose the effect of branch closures along four types of credit: short term credit (i.e., credit with an initial maturity lower than one year), long term credit, total drawn credit (which includes both previous types of credit as well as leasing) and undrawn credit. If branch closures relax credit constraints, we should expect some type of drawn credit to increase following a branch closure. On the contrary, if firms benefit from the closure to deepen the credit usage, the

[33]For instance, if firms are more likely to survive because they benefited from a credit renewal during the period than because they held long maturity credit, constraining cohorts to include both controls introduces a negative bias in our estimate.

[34]They are treated borrowers which are still in the credit registry, and which have at least one control firm present, 2 years after closure.

effect should, at least partially, be driven by an increase in undrawn credit lines.

Table 6 displays the estimation of Eq.(2.2), differentiating along the different credit types. Clearly, branch closures lead to an increase in the amount of undrawn credit, which rises by 10% on average during the two years after the closure. In comparison, neither short term nor long term credit change, suggesting that borrowers benefit from their branch closure to smooth, if any, negative shocks on their credit usage, and also to engage in new credit contracts which serve as additional liquidity reserves.

In Table 7, we provide a more detailed picture of the consequences of branch closures on firms' credit allocation, by interacting our variable of interest *Post* in Eq.(2.2) with a dummy variable, which equals one if the treated firm in the cohort had no undrawn credit before the closure. [35] Because these firms are more likely to face initial credit constraints and less intense credit usage, we expect branch closures to have little effect on their credit usage, if firms mostly benefit from branch closures to expand their credit lines, and not to relax initial financial constraints. The results in Table 7 show that the increase in total credit is twice lower for these firms, with an average increase of their credit of only 1.6%, against 4.5% for firms which already had undrawn credit before closure. Firms with no initial undrawn credit experience a strong decrease in their long-term credit after closure, which suggest they are hurt by the severance of their branch relationship. However, they smooth this negative effect by increasing their short-term credit usage as well as their credit lines. On the contrary, firms which had some undrawn credit before closure (either because they were less credit constrained or because they had more frequent credit usage) are able to increase significantly their credit. Following a closure, they are also able to borrow at longer maturities, and to draw more credit by and large.

4.4 Heterogeneity analysis

From the previous section, it appears that the firms which increase their credit amount following branch closure were less credit constrained before closure, or they differ from other firms by also using credit as a liquidity facility. We now study how the intensity of this effect varies with firms' characteristics. In Table 8, we take advantage of our matching strategy, and we estimate the model in Eq.(2.2) separately on subsamples of cohorts with identical matching firms' characteristics (as listed in Table 3a). Given that the specification in Eq.(2.2) estimates within-cohort differences, this enables us to study the effect of branch closure on firms with identical characteristics before the closure[36].

[35] 60% of treated firms belong to this category, while 40% had some undrawn credit lines at some point during the 7 quarters that precede the branch closure.

[36] One of the characteristic we use is specific to treated borrowers (i.e., whether the closed branch was the firm's main branch). In this case, the matching variable on the number of banking relationships at the time of closure enables us to compare similar firms.

Number and intensity of banking relationships We estimate Eq.(2.2) separately on cohorts with multiple (column (1)) and single (column (2)) banking relationships before the closure date. In line with Degryse, Masschelein, and Mitchell (2010), we find that firms with multiple relationships are better prepared to regain credit access following a shock on one of their banking relationship. In contrast to them, in our estimations, single-relationship borrowers also experience, to some extent, an increase in their credit amount following a closure. Overall, this provides some evidence that borrowers can effectively maintain their access to credit following a transfer to another branch, though it is also likely that firms' decision to maintain a unique banking relationship is determined endogenously. In columns (3)-(4), we show that firms with multiple relationships remain unaffected by the closure, if the closed branch is not their main branch during the quarter of closure.

Risk and corporate group affiliation Second, we show in Table 8 that borrowers categorized as risky by the Banque de France notation do not benefit from a significant increase in their credit amount following a closure, unlike other borrowers. However, they do not face additional credit constraints following their branch closure neither. On the other side of the risk spectrum, borrowers with good credit notations do not benefit from specific risk premia following a closure, with respect to the average borrower. Therefore, the effect of branch closure on access to credit is insensitive to differences in public information on borrowers' risk, such that the increase in credit amounts cannot be attributed to corrections on risk mispricing by closed branches.

Third, the effect of branch closure is slightly higher for firms which belong to a group, which may suggest that firms of the same group benefit from small synergies by regrouping under the same roof following closure.

Urban location Finally, in columns (9) and (10), we compare the effect of a branch closure between cohorts which hold credit from urban branches and those which hold credit from rural branches before a closure. Importantly, the increase in credit following a branch closure is three times larger when the borrower is related to a urban branch, than when it is related to a rural branch, with an average increase during the two years after closure of 4.8% against only 1.5%. In addition, the effect of branch closure in rural areas is only significant at the 5% level. Thus, the increase in loan amounts following a closure strongly depends on the location of firms' branches. We analyze in more details the importance of this geographical discrepancy, and the role of branch presence, in Section 5.

4.5 Robustness checks

We first add an additional matching criteria to our matching sample, in order to dismiss remaining concerns that our result is driven by remaining differences in credit volumes between our treated and control groups. Indeed, our initial matching procedure only distinguish borrowers who only hold long-term credit from others, and we chose not to reduce too much the heterogeneity in the level of credit (see the discussion in the methodology section). As a consequence, treated borrowers hold shorter maturities than other borrowers in our sample, and they borrow slightly more in general. As a robustness check, we focus on borrower with similar credit volumes along all credit categories, by keeping matched cohorts where borrowers hold with very similar total credit amonts.[37] In Table 3c, we show that our sample now exhibits no difference in the level of type of credit at the quarter before the date of closure. In Figure 4, we estimate Eq.(2.1) on this restricted sample. Our main result remains unchanged: seven and eight quarters after their branch closed, the differences in the credit volumes of treated borrowers within cohorts reach respectively 6% and 7%.

In Table 9, we run additional robustness checks to address some potential caveats of our previous estimation. First, following a branch closure, competing local banks may increase the credit to all borrowers. In this case, our estimation would not track the effect of branch closure on its borrowers as such, but on all borrowers of the banking group. To test this possibility, we re-estimate Eq.(2.2) including bank-period-date fixed effects (where periods represent the quarterly distance to closure $\tau \in T$ in Eq.(2.2), and date refers to the calendar quarter), such that we control for credit variations at the bank level for each quarterly wave of branch closures separately. One drawback of this estimation is that these fixed effects absorb the effect of branch closures β_{post}, when a main bank is not represented, in each wave of branch closures, by both some treated and control borrowers. As a consequence, our estimate decreases to 2%, but it remains significative at the 1% level.

It is also possible that the reorganization of branch network is induced by a strategy to specialize in growing industries. Therefore, the relative increase in credit amounts may occur because borrowers from local non-closed branches of the same bank are the de facto excluded from the reorganization. To better account for industry variations in credit across various banks, in column (2) of Table 9 we also estimate Eq.(2.2) including industry-period-date fixed effects. Results remain unaltered, with an average increase of 3.1% of credit during the two years after closure.

The reorganization of a banking group may come together with a progressive rationalization of branches portfolio. Therefore, outstanding credit which was granted in different branches of the same banking group may be gradually pooled within a single branch. As we only observe banking relationships above 25k€, it is possible that the increase in borrower credit stems from the aggregation of borrower's outstanding credit across different branches of the same banking group, such that borrowers' credit which was below the declaration

[37] For each matched cohort, we estimate a two-sample t-test for the total amount of credit during the quarter before closure, and we keep cohorts where the t-stat of the difference is lower than 1/3, as heterogeneity along all types of credit disappear below this threshold.

threshold becomes reported at some point after the closure.[38] To tackle this potential bias, in column (3) of Table 9, we do not consider branch closures from banks which declared, at any month during our sample period, multiple branches to more than 1% of their borrowers.

Finally, in columns (4) and (5) we check that our result is not driven by the largest firms in our dataset. We first reproduce the estimation of Eq.(2.2), excluding treated borrowers (and their cohort) if they ever get more than 2M€total credit during our period of estimation. Our estimation of the effect of closure slightly decreases, partly because we exclude mostly borrowers who still hold credit during all of our estimation window but remain qualitatively unchanged, with a significant average increase of 2.4%. Alternatively, we exclude the treated borrowers who belong to the mid-cap category. In this case, we still find that the branch closure leads to an average increase in the outstanding credit of around 3%.

5 Analysis: expertise or renegotiation effects?

In this section, we discuss potential mechanisms which could drive our results. As explained in the introduction, we distinguish two potential effects.

First, following reorganization, new loan officers may be better equipped or skilled to assess credit risk, such that previously constrained firms can obtain larger amounts of credit, or roll-over their cash-flow facilities more easily. When taking over the portfolio of the closed branch, new loan officers are then able to fit firms' financial needs better, implying a higher use of debt financing. We call this mechanism the *expertise effect*. This mechanism is driven by the supply of credit from the receiving branch. It suggests that information is transferable across branches of the same banking group, and that it can be used more efficiently by new branches. Alternatively, borrowers may benefit from the closure to renegotiate their credit conditions with the new branch, or to seize the opportunity of the closure to switch to another lender. We call this mechanism the *renegotiation effect*. This mechanism is mostly driven by the firms' demand, and it suggests that information is transferable to outside banks as well as within the banking group.

5.1 Effect of closed branches from merged banks

To disentangle between the two mechanisms, we first compare the results of the previous section, which focused on branch closures within stable banking groups, with the effect of branch closure following the merger (or the sale) of the banking group (the merged

[38] For instance, if a borrower had 10 k€in the takeover branch before closure, this amount of credit is only reported in the credit registry after the outstanding credit from the closed branch, which was by definition higher than 25k€, is transferred.

bank) to a bigger institution (the absorbing bank).[39] Our reasoning is that the *expertise gains* are a priori more important following a change in bank ownership than for a simple branch transfer, while the ability of borrowers to *renegotiate* are either unchanged or lower, depending on the negative effect of the merger on local banking competition. Thus, if the *expertise effect* is dominant, we expect borrowers from these closed branches to borrow more after merger than control borrowers from the same bank in the first months following merger, as they can benefit immediately from the adoption of the absorbing bank technology. However, if the *renegotiation effect* dominates, we expect to see no difference or a negative effect for borrowers from a closed branch with respect to others borrowers, depending on their respective incentives to renegotiate, the disruption in past relationships, and the effect of the merger on local competition.

For this purpose, we estimate the model given in Eqs.(2.1) and (2.2) on the branches closed in the last quarter before their banking group disappears from the credit registry. During our period, we observe in the credit registry 30 branches of banks have been closed during our period following the merger of their banking group.[40]

We first provide some evidence that, at the bank level, the transfer leads to a reassessment by the absorbing bank of its newly acquired portfolio. For this purpose, we reproduce the matching procedure described in Section 2, only excluding bank identity from the matching variables, such that we compare borrowers from the merged bank with similar borrowers from other banks. In Figure 5, we then report the results of the estimation of Eq.(2.1), using real-property leasing and movable-property leasing amounts as dependent variables. As opposed to other types of credit, leasing may require specific scrutiny, for instance in the identification of the goods acquired. This scrutiny is especially valid for movable properties, as they imply bank ownership of multiple, wearable goods.[41] Figure 5 highlights that receiving banks delay 40% of the reporting of movable-property leasing contracts in the quarter after transfer, while they report real-property leasing contracts on the spot. Even though we do not estimate expertise gains from bank merger directly, this highlights that the absorbing bank either uses a delay for screening the former contracts, or that the reporting of specialized, merged institutions is partially incompatible with the one of absorbing banks. In both cases, this implies that borrowers from the merged banks are likely to be affected by changes in bank organization.

We next estimate the specific effect of the merger at the branch level, depending on

[39]We do not identify mergers from sales, such that we use both terms interchangeably. We define a closure to be due to a merger/a sale if the closure happens in the last quarter before the bank exists the credit registry.

[40]We follow the same definition used for other branches to discriminate changes in the ID of branches from effective closures. See Section "Definition".

[41]As a consequence, in French Law, all movable-property leasing contracts must be recorded to the competent judicial authority, while the recording of real-property leasing depends on the terms of the contract (*Code monétaire et financier*, Articles R313-4 to R313-11).

the takeover or the closure of the branch by the new banking group. Using the matching procedure of Section 2, we match borrowers from the closed branches with borrowers from other branches of the same merged bank.[42] Thus, our matching procedure isolates the common effects of a merger on all merged borrowers from possible heterogeneous effects at the branch level. In Figure 6, we report the results of the estimation of Eq.(2.1) for both types of leasing contracts. We confirm that the higher scrutiny towards movable-property leasing contracts operates at the bank level, as the difference between borrowers depending on their branch closure is not significant. In Figure 7, we report the result of Eq.(2.1) for all credit amounts. We observe no different effects of the merger between borrowers from closed branches and other borrowers. Therefore, if the merger generates expertise effects at the branch level, borrowers from closed branch do not appear to experience stronger efficiency benefits. Comparing with the effect of closure in when the banking group remains unchanged, the positive effect of closure is canceled when the closure follows a merger. As a consequence, the positive effect of branch closures on credit amounts exists only when the closures preserves local credit competition, which indicates that branch closures generate *renegotiation effects.*

5.2 Supply-side effects

Focusing again on closed branches by a lasting banking group, we now identify if firms experience a higher credit increase from their receiving branch than for competing banks. If this is true, this will support the existence of *expertise effects* following a closure. On the contrary, if branch closures generate no positive supply effects, this will suggest that borrowers from closed branches are able to regain access to credit from various banks, in line with the presence of *renegotiation effects*.

We collapse our dataset at the firm-bank level.[43] For comparison purposes, we estimate supply effects on the treated borrowers who were matched in Section 3.[44] In line with Khwaja and Mian (2008), we estimate the effect of closure on within-firms credit variations, using

$$\log(1 + Y_{ib\tau}) = \Sigma_{\tau \in T} \beta_\tau C_{ib\tau} + \lambda_{i\tau} + \eta_{ib} + u_{ibt}, \tag{2.3}$$

with $C_{ib\tau} = 1$ if the banking group b of firm i had experienced a branch closure before or during quarter τ, with firm i a borrower with multiple banking relationships.

We also assess the average effects of a branch closure on credit supply within bank, by aggregating post-treatment coefficients β_τ in Eq.(2.3) and estimating the following two-

[42] Unlike our initial matching procedure, we therefore require an exact matching on a relationship with the bank which failed, and not only on any common banking relationship.

[43] Sometimes, we observe that credit is transferred to another bank, and we collapse our dataset at both banks together for these firms. Visual inspection suggests this is most likely due to transfers among regional cooperative banks of the same banking group.

[44] The results of this section continue to hold if we include all treated borrowers.

way-fixed effects model:

$$\log(1 + Y_{ib\tau}) = \beta_{post} PostC_{ib\tau} + \gamma X'_{ib\tau} + \lambda_{i\tau} + \eta_{ib} + u_{ibt} \tag{2.4}$$

with $PostC_{ib\tau} = 1$ if borrower i already experienced a closure at quarter τ from bank b. Here, the coefficient β_{post} represents the average change in credit amount after a branch closure from the same bank, with respect to the other banks.

Figure 8 provides a graphical representation of the estimation of Eq.(2.3). In all periods in the two years following a closure, borrowers experience no change in the credit supply from the bank of the closed branch. The supply of credit only begins to decrease slowly 6 quarters after the closure, and this variation remains non-significant.

In Table 10, we estimate Eq.(2.4), and we similarly show that the average credit supply from the bank which decided closure is unaffected by the branch closure during the two years after the event. In column (2), we add bank control variables to the estimation of Eq.(2.4), in order to control for differences across banks before closure. In column (3), we estimate long-term effects, by keeping only firms' credit amount by bank during our benchmark quarter and two years after the closure. In all cases, we estimate a negative but non-significant effect of branch closure on the supply of credit. The heterogeneity analysis performed in Table 11 highlights that the absence of supply effects from the bank initiating the closure holds for different types of borrowers, with only risky or independent firms experiencing a small negative supply shock, following their branch closure.

In Figure 9, we distinguish the supply effects of branch closures on drawn and undrawn credit amounts. Clearly, the receiving branch re-denominates some credit, which was previously recorded as drawn, into undrawn credit. Even if it remains small in volume, the amount of undrawn credit jumps by 40% on average in the quarter following a closure, and it continues to increase in the two years after. On the contrary, drawn amounts continuously decrease with respect to other banks. Therefore, it appears that receiving branches are indeed more efficient, in the sense that it fine-tunes the declaration of off-balance commitments on specific borrowers. This may be beneficial for the bank, as well as for borrowers, by decreasing their debt. However, receiving branches do not increase their credit supply to transferred borrowers more than other branches, suggesting that this potential benefits are split among branches. As a consequence, the overall increase in credit identified in Section 2 is most likely due to renegotiation effects, where the borrower benefits from the closure to increase its amount of credit.

5.3 Local market competition

If some borrowers take advantage of their branch closure to renegotiate their credit conditions, their ability to leverage on their specific positioning depends on local credit market competition, foremost, on the number of alternative lenders available. On the contrary, if the receiving branch is able to provide additional services to borrowers, or if branch closures is endogenous to local credit competition, the presence of alternative branches has no effect or a negative effect, respectively, on the ability of borrowers to increase their credit exposure following a closure.

To test for the effect of local branch presence on the effect of branch closure, in the top section of Table 12, we interact our variable of interest $PostC_{i\tau}$ in Eq.(2.2) with a dummy variable, which equals 1 if the treated borrower i has a number of branches around him in the quarter before closure which is below the median of treated borrowers.[45]

We first consider the effect of the number of local branches belonging to the bank deciding of the branch closure. Results in column (1) highlight that borrowers benefit from the closure only when their bank has little local presence. Therefore, borrowers only increase their credit following closure if the local network of their receiving branch is small, such that borrowers are more likely to benefit from high negotiation power over their receiving branch. In column (2), we focus on cohorts matched because they are engaged in a relationship with a rural branch, and we similarly split cohorts depending on the number of branches of the treated borrower before closure. The competitive pressure of a small local network disappears, which suggest that the effect is only valid within urban areas.

In columns (3)-(4), we study the effect of the number of local branches which do not belong to the banking group deciding of the branch closure, before considering in columns (5)-(6) the total effect of the number of local branches. In both cases, the increase in credit after closure strongly depends on the presence of alternative local branches. More precisely, borrowers with high presence of alternative local branches increase their credit by 5%, while other borrowers do not experience changes in their credit volume. This heterogeneity remains when we focus on rural areas, such that it does not only represent differences between urban and rural credit markets. In rural areas, borrowers experience a credit increase of 3% with respect to other borrowers of the same cohort, but only if they belong to more dense branch networks.

Finally, in the bottom section of Table 12, we reproduce the same analysis, but extend the perimeter of local markets to include adjacent towns.[46] Results remain unchanged, which suggest that the effect of local branch network is robust to different definitions of local credit markets.

[45]The number of branches is computed at the firm level, such that it represents the average number of branches in the neighborhood of the each branch in relationship with the firm, weighted by the proportion of credit of the firm hosted by each branch.

[46]Therefore, borrowers located in suburban areas are more likely to be belong to dense branch networks, and borrowers from small cities are more likely to be located in small branch networks.

5.4 Discussion and external validity

Our results contradict the hypothesis that the losses of credit relationships during branch closures, coupled with the increasing distance between borrowers and lenders, exert negative effects on borrowers' access to credit. On the contrary, we show that borrowers benefit from their branch closures to increase their amount of available credit. Below, we suggest three reasons why borrowers in general may not be harmed by the closure of their branch, by comparing branch closures with other types of changes in banking relationships.

First, unlike new borrowers, borrowers from a closed branch already proved to be involved in a credit relationship. Their success in the screening procedure of their former bank(s), together with the availability of credit records, limits their costs of starting a new banking relationship for these borrowers and their lenders (Agarwal et al., 2021). Second, unlike borrowers who switch credit provider, they benefit from a credible motive to engage in a new banking relationship. Therefore, a greater distance between the branch and the borrower no longer provides a bad signal to the lender on the credit risk of the borrower. Third, unlike borrowers who settle in a foreign country, their financial statements as well as current credit lines are transferred to their new branch, which enables them *de facto* to build a new credit relationship. Finally, setting aside the potential specificities of borrowers from closed branches, progress in screening technologies as well Internet banking adoption by borrowers (Xue, Hitt and Chen, 2011) may reduce the importance of soft information in explaining borrower access to credit.

In addition to the specific characteristics of transferred borrowers, contextual considerations help explaining the positive credit effects of branch closures in recent years in France. First, we detail how the effect of branch closure depends on the density of local branch networks. From an international perspective, France has a dense branch network, with more than 90% of branch closures in our sample being located in towns with at least 3 other branches.[47] Also, our results suggest that borrowers may not benefit from their branch closures, depending on the cause of the branch closure (reoganization or merger). Finally, corporate borrowers faced few credit constraints during our period of analysis. For instance, in the second semester of 2017, 86% (resp., 95%) of SMEs declare to have been granted at least 3/4 of their loan demand for cash flow management and investment, respectively (Banque de France and FCGA, 2017). Therefore, branch closures are likely to exacerbate the effect of macro-economic conditions on treated borrowers (Nguyen, 2019).

Our results highlight that relevant information for credit access is transferable both within the same banking group (through transfer of financial data and reports on borrowers in the form of notes or recommendations), and to another banking group. In line with Petersen and Rajan (2002), this suggests that improvements in screening technologies limit the importance of soft information. However, the existence of a positive shock of

[47]For comparison, 20% of branch closures in the US during the 2010s happened in censuses where no branch remained afterwards (Nguyen, 2019).

the closures on borrowers' ability to increase their usage of credit lines underlines that transaction and search costs remain important hurdles which prevent borrowers from fully exploiting local competition on a regular basis.

6 Conclusion

Using a combination of matching and differences-in-differences, we provide evidence that borrowers increase their outstanding credit following the closure of their branch. This effect is long-standing, such that borrowers experience a 6% increase in their loan amount two years after the closure. In addition, we show that this effect is not driven by a specific increase in the supply of credit by their receiving branches. We suggest that borrowers from the closed branch take advantage of the closure to increase their credit requests, as they benefit from a privileged position with respect to other borrowers. Our results highlight that the existence of previous banking relationships are valuable information for both the bank of closure and outside banks. The intensity of this effect depends on local competition, which shapes borrowers' ability to apply for higher amounts of credit, as well as banks' willingness to invest in new relationships.

From a policy perspective, our results highlight that branch closures benefit borrowers under favorable credit environments, while it suggests in contrast that borrowers may not fully take advantage of local credit competition on a regular basis. Therefore, it remains unclear whether the increase in credit usage compensates for the other costs of changing branch, and if borrowers also benefit from lower interest rates. Also, this leaves aside important considerations regarding the effect of branch closures at the extensive margin, and their spillover effects on other branches and borrowers.

Bibliography

[1] Agarwal, S., & Hauswald, R. (2010): "Distance and private information in lending," *The Review of Financial Studies*, 23(7), 2757–2788.

[2] Agarwal, S., Kigabo, T., Minoiu, C., Presbitro, A.F. & Silva, A.F. (2021). "Serving the underserved: microcredit as a pathway to commercial banks," *The Review of Economics and Statistics*, 10, 1-45.

[3] Alama, L., Conesa, D., Forte, A. & Tortosa-Ausina, E. (2015): "The geography of Spanish bank branches," *Journal of Applied Statistics*, 42(4), 722–744.

[4] Albertazzi, U., Becker, B. & Boucinha, M. (2021): "Portfolio rebalancing and the transmission of large-scale asset purchase programs: Evidence from the Euro area," *Journal of Financial Intermediation*, 48, 100896.

[5] Australian Treasury (2022): "Regional Banking Taskforce - Final Report," *Report to th Australian Treasury*, September 2022.

[6] Banque de France & Fédération des centres de gestion agrées. (2017): "Enquête Accès des entreprises au crédit", 2017(Q3).

[7] Bertrand, M., Duflo, E. & Mullainathan, S. (2004): "How much should we trust differences-in-differences estimates?", *Quarterly Journal of Economics*, 119(1), 249-275.

[8] Betz, F. & De Santis, R.A. (2019): "ECB corporate QE and the loan supply to bank-dependent firms," *SSRN Working Paper*, 3453159.

[9] Bonfim D., N, Nogueira, G., & Ongena, S. (2021): "Sorry, We're Closed: Loan Conditions When Bank Branches Close and Firms Transfer to Another Bank," *Review of Finance*, 25(4), 1211–1259.

[10] Boruskak, K. & Jaravel, X. (2017): "Revisiting event study designs," *SSRN Working Paper,* 2826228.

[11] Bolton, P., Freixas, X., Gambacorta, L. & Mistrulli, P.E. (2016). "Relationship and transaction lending in a crisis", *Review of Financial Studies*, 29(10), 2643–2676.

[12] Brignall, M. (2019): "More than a third of UK bank branches have closed since 2015", *The Guardian.*

[13] Carling, K. & Lundberg, S. (2005): "Asymmetric information and distance: an empirical assessment of geographical credit rationing," *The Journal of Economics and Business*, 57(1), 39–59.

[14] Cengiz, D., Dub, A., Lindner, A., & Zipperer, B. (2019): "The effect of minimum wages on low-wage jobs," *The Quarterly Journal of Economics*, 134(3), 1405-1454.

[15] Chabé-Ferret, S. (2017): "Should We Combine Difference In Differences with Conditioning on Pre-Treatment Outcomes?," Toulouse School of Economics Working Paper, 17-824.

[16] Daw, J.R. & Hatfield, L.A. (2018): "Matching and regression to the mean in difference-in-differences analysis," *Health services research*, 53(6), 4138–4156.

[17] Degryse, H., & Ongena, S. (2005): "Distance, lending relationships, and competition," *The Journal of Finance*, 60(1), 231–266.

[18] Degryse, H., Kim, M. & Ongena, S. (2009): "Microeconometrics of banking: methods, applications, and results," *Oxford University Press.*

[19] Degryse, H., Masschelein, N., & Mitchell, J. (2011): "Staying, dropping, or switching: the impacts of bank mergers on small firms," *The Review of Financial Studies*, 24(4),

1102-1140.

[20] Detragiache, E., Garella, P. & Guiso, L. (2000).: "Multiple versus single banking relationships: Theory and evidence," *The Journal of Finance*, 55(3), 1133–1161.

[21] Devreux, C. (2019): "Santander to Shut Fifth of U.K. Branches, Lay Off at Least 800 People," *Bloomberg.*

[22] DeYoung, R., Evanoff D.D. & Molyneux, P. (2009). "Mergers and acquisitions of financial institutions: A review of the post-2000 literature," *Journal of Financial Services Research*, 36(2), 87–110.

[23] Dick, A.A., (2008): "Demand estimation and consumer welfare in the banking industry.," *Journal of Banking & Finance*, 32(8), 1661–1676.

[24] Di Patti, E.B. & Gobbi, G. (2007): "Winners or losers? The effects of banking consolidation on corporate borrowers," *The Journal of Finance*, 62(2), 669–695.

[25] Drexler, A. & Schoar, A. (2014): "Do relationships matter? Evidence from loan officer turnover," *Management Science*, 60(11), 2722–2736.

[26] Duquerroy, A., Mazet-Sonilhac, C., Mesonnier, J-S. & PARAVISINI, D. (2022): "Bank Local Specialization," *Sciences-Po Working Paper,* 865.

[27] Ergungor, O. E. (2010): "Bank branch presence and access to credit in low- to moderate-Income neighborhoods," *Journal of Money, Credit and Banking*, 42(7), 1321–1349.

[28] Financial Conduct Authority (2018): "Strategic Review of Retail Banking Business Models - Annexes to the Final Report," *FCA Reports*, Annex 1.

[29] Funk, A. K. (2019): "Quantitative easing in the euro area and SMEs access to finance: Who benefits the most?," *Graduate Institute of International and Development Studies Working Paper*, 2.

[30] Garri, I. (2019): "The effects of bank branch closures on credit relationships," *Banca d'Italia Working Paper*, 1254.

[31] Goodman-Bacon, A. (2021). Difference-in-differences with variation in treatment timing. *Journal of Econometrics*, 225(2), 254-277.

[32] Granja, J., Leuz, C. & Rajan, R.G. (2022). "Going the extra mile: Distant lending and credit cycles," *The Journal of Finance*, 77(2), 1259–1324.

[33] Ho, C. S. T., & Berggren, B. (2020): "The effect of bank branch closures on new firm formation: the Swedish case", *The Annals of Regional Science*, 65(2), 319-350.

[34] Houston, J. & James, C. (1996): "Bank information monopolies and the mix of private and public debt claims", *The Journal of Finance*, 51(5), 1863–1889.

[35] Keil, J. & Ongena, S. (2021): "The Demise of Branch Banking Technology, Consolidation, Bank Fragility," Swiss Finance Institute Research Paper Series, 20(83).

[36] Khwaja, A.I. & Mian, A. (2008): "Tracing the impact of bank liquidity shocks: Evidence from an emerging market," *American Economic Review*, 98(4), 1413–42.

[37] Lederer, E. (2020): "Banques : pourquoi les fermetures d'agences vont s'accélérer en France," *Les Echos.*

[38] Nguyen, H-L Q. (2019): "Are credit markets still local? Evidence from bank branch closings," *American Economic Journal: Applied Economics*, 11(1), 1-32.

[39] Martin-Oliver, A. (2019): "Financial exclusion and branch closures in Spain after the Great Recession," *Regional Studies*, 53(4), 562–573.

[40] Martin-Oliver, A., Toldra-Simais, A., & Vicente, S. (2020): "The real effects of bank branch closings and restructurings," *SSRN Working Paper*, 3644878.

[41] Ongena, S., Smith, D. C., & Michaelsen, D. (2003): "Firms and their distressed banks: lessons from the Norwegian banking crisis," *Journal of Financial Economics*, 67(1), 81–112.

[42] Panetta, F., Schivardi, F. & Shum, M. (2009): "Do mergers improve information? Evidence from the loan market," *The Journal of Money, Credit and Banking*, 41(4), 673–709.

[43] Petersen, M.A. & Rajan, R.G. (1994): "The benefits of lending relationships: Evidence from small business data," *The Journal of Finance*, 49(1), 3–37.

[44] Petersen, M.A. & Rajan, R.G. (2002): "Does distance still matter? The information revolution in small business lending.," *The Journal of Finance*, 57(6), 2533–2570.

[45] Rajan, R. G. (1992): "Insiders and outsiders: The choice between informed and arm's-length debt," *The Journal of Finance*, 47(4), 1367–1400.

[46] Sharpe, S. A. (1990): "Asymmetric information, bank lending, and implicit contracts: A stylized model of customer relationships," *The Journal of Finance*, 45(4), 1069–1087.

[47] Temesvary, J. (2015): "Dynamic branching and interest rate competition of commercial banks: Evidence from Hungary," *International Journal of Industrial Organization*, 43, 98–110.

[48] Von Thadden, E. L. (2004). "Asymmetric information, bank lending and implicit contracts: the winner's curse," *Finance Research Letters*, 1(1), 11–23.

[49] Xu Y., Saunders, A., Xiao, B., & Li, X. (2020): "Bank relationship loss: The moderating effect of information opacity," *Journal of Banking & Finance*, 118(105872).

[50] Xue, M., Hitt L.M., & Chen P-Y.(2011): "Determinants and outcomes of internet banking adoption." *Management Science,* 57(2), 291-307.

[51] Zhang, A.T. (2020): "Estimation of high-dimensional dynamic games: Fintech lenders and bank branch closures," *Havard University Working Paper.*

7 Appendix - Tables

Table 1 - Construction of the closed branch dataset

We have access to two complete extracts from the branch directory of universal banks, made in July 2018 and in May 2021. We define closed branches and date as follows:

Information on branch	Effective date of closure d_I, with
Declared closed in our directory at date F	I=(F-18 months, F)
Active in the first directory extract only	I=(Aug.18, Mar.20)
Absent from directory, banking group present	I=(Mar.15, Feb.17)
Bank absent from directory, branch exits from credit registry	I=(Jan.15, Mar.20)

and d_I represents the date of the largest drop in the number of borrowers, if any, during period I.

Table 2a - Descriptive statistics at the branch level

	Closed				Receiving				All other			
	Mean	*p*10	*p*50	*p*90	*Mean*	*p*10	*p*50	*p*90	*Mean*	*p*10	*p*50	*p*90
Credit:												
# Firms	41	2	11	64	83	5	33	141	86	5	30	144
Total loan	10	0	1	11	40	1	5	40	42	1	4	36
Short term	1.40	0	0.08	1.32	5.71	0.01	0.24	3.90	5.28	0	0.25	3.36
Long term	7.69	0.12	1.14	7.91	27.83	0.50	4.17	31.53	26.77	0.39	3.50	25.89
Undrawn	0.67	0	0.02	0.69	6.27	0	0.11	2.96	6.80	0	0.20	3.35
Borrower:												
Single	0.72	0.43	0.75	1.00	0.69	0.44	0.72	0.91	0.68	0.39	0.72	0.90
# relat. firm	1.50	1.00	1.33	2.00	1.59	1.10	1.40	2.18	1.65	1.11	1.40	2.38
# Duration relat.	50	21	49	78	48	21	49	72	58	27	57	90
Local:												
Urban	0.46	0	0	1.00	0.53	0	1.00	1.00	0.38	0	0	1.00
# oth. BT	33	2	13	103	40	4	19	124	29	2	9	92
# oth. BBT	5	1	2	12	6	1	2	16	4	1	1	10
HHI	3614	1084	2652	8637	2791	1032	2110	5461	3788	1143	2837	9466
Observations	24948				30753				429053			

Note: The sample period is 2015 Q1 to Q1 2020 Q1. For receiving branches, statistics are computed before they receive their first transferred branch. Credit variables are in euro millions. Short term credit represents outstanding credit with initial duration below one year. Duration variables in months. Urban equals one for branches located in cities > 50.000 inhab., or in communes adjacent to cities > 100.000 inhab. Here, closed branches happened independently of any merger or sale of their banking group. We exclude receiving branches if their transferred branch did not appear in the Credit Registry.

Table 2b - Descriptive statistics at the firm level

	Treated d. period					Not treated d. period				
	Mean	p10	p50	p90	SD	Mean	p10	p50	p90	SD
Total loan	1246	32	150	1292	16901	593	29	93	609	12123
Drawn Credit	1081	28	135	1145	14626	503	25	82	546	9686
Undrawn Credit	163	0	0	108	3912	87	0	0	50	4646
Short term ST	184	0	0	159	2125	73	0	0	50	1752
Long term LT	816	0	85	705	13687	390	0	58	414	9062
Off balance sheet	254	0	0	240	5682	123	0	0	82	5399
Single	0.56	0	1	1	0.50	0.77	0	1	1	0.42
Age firm	91.04	21	99	150	46.88	82.89	12	93	147	48.43
# relat. firm	1.96	1	1	4	1.73	1.36	1	1	2	0.91
# Duration relat.	49.58	6	42	105	37.34	59.01	6	51	123	43.35
Urban	0.54	0	1	1	0.50	0.49	0	0	1	0.50
Observations	1,134,309					27,294,252				

Note: The sample period is 2015 Q1 to Q1 2020 Q1. Credit variables are in euro thousands. Short term credit represents outstanding credit with initial duration below one year. Duration variables in months. Urban equals one for branches located in cities > 50.000 inhab., or in communes adjacent to cities > 100.000 inhab. Treated borrowers here only experience branch closures independently of any merger or sale of their banking group. Statistics are computed before matching.

Table 3a - Variable used for matching

Variable	#	Definition
		Exact matching
Date	63	Presence in the credit registry at month -3 before branch closure
Firm		
Industry	10	NACE 10 rev2: we exclude subcategories from public administration, and most real estate firms (*Societes Civiles Immobilieres*)
Group	4	Holding, subsidiary, branches, or independent
Risk	6	Credit score defined by the Banque de France (see last column of table next page)
Credit		
Bank	670	Same bank (may not be the bank of the closed branch)
Long term	2	Dummy = 1 if firm has no credit with maturity < one year
Single	2	Dummy = 1 if firm has only one bank relationship
Borrow	3	Higher / lower volume of credit than a year before date Had no outstanding loan a year before matching date
Date of credit termination	-	Year of termination in the Credit Registry (year on year, until 30 months after date)
Geo branch		
City	2	Dummy = 1 if the branch is located in a city with more than $50,000$ inhab., or in a close neighbour town.
		Closest matching
Total credit	-	Total outstanding debt excluding financial guarantees to third parties
Location	-	Branch town / County / State

Notes: For each matching variable, we report in the second column the number of different categories in our dataset. Firms with multiple relationships may belong to more than one group, as geographical variables are defined at the branch level. In this case, we select the most frequent location and urbanity of branches'firm at the matching date, and select randomly in case of equality.

For firms belonging to the same category (on Exact Matching variables) and to the same town as the treated firm, we select the two control firms with the closest level of credit. If this is not enough, we extend the search to firms from the same county, and then from the same region, and finally to all firms.

Table 3b - Credit score ratings by the Banque de France

Credit score	Description: The firm's ability to meet its financial obligations is deemed:	Procedure probability	Groups used for matching
3 + +	Excellent	0.04%	
3+	Very good	0.08%	*Very good*
3	Good	0.16%	
4+	Quite good: little financial imbalances reported	0.52%	*Average good*
4	Fair: moderate factors of uncertainty or fragility	1.37%	
5+	Fairly good	3.46%	
5	Poor	8.18%	*Average*
6	Very poor	12.42%	
7	At least one reported payment incident	25.95%	
8	At risk given the payment incident reported	33.50%	*Risky*
9	Compromised: severe cash flow problems	41.80%	
P	Subject to insolvency proceedings	–	*Insolvent*
0	No evaluation by the B.D.F for the period	0	*Not rated*

Note: for each credit score category, we report the predicted probability of procedure (default) over a three-year horizon between 2017 and 2019.

Table 3c - Comparison between treated borrowers and control group on firms' variables absent from the (exact) matching

	Benchmark matching (no match on credit level)			Robustness matching (match on credit level)		
	Treated mean/sd	Control mean/sd	Diff b/se	Treated mean/sd	Control mean/sd	Diff b/se
Total loan	1635	1370	265.15**	1335	1393	-57.86
	(20049)	(17356)	(130)	(12796)	(18053)	(258)
Drawn Credit	1411	1204	206.28*	1223	1259	-36.41
	(16989)	(15828)	(115)	(12256)	(17214)	(246)
Undrawn Credit	224	165	59.21**	113	134	-21.44
	(5093)	(15828)	(29)	(927)	(1333)	(19)
Short term ST	240	183	57.36***	186	197	-11.13
	(2281)	(1939)	(14)	(1548)	(2795)	(38)
Long term LT	1058	925	132.24	943	967	-23.74
	(16046)	(15012)	(109)	(11682)	(16644)	(237)
Off balance sheet	388	232	155.69**	177	201	-24.01
	(14616)	(3977)	(64)	(1465)	(1793)	(26)
Age firm	94.53	94.41	0.12	94.74	94.81	-0.07
	(47.58)	(47.51)	(0.34)	(47.58)	(47.51)	(0.34)
# relat. firm	2.37	2.16	0.21***	2.34	2.18	0.16***
	(2.02)	(1.64)	(0.01)	(1.90)	(1.69)	(0.03)
# Duration relat.	69.99	70.15	-0.16	70.55	70.61	-0.06
	(48.11)	(48.24)	(0.34)	(48.16)	(48.40)	(0.76)
Months aft. clos.	39.71	39.58	0.13	39.81	39.68	0.13
	(14.56)	(14.60)	(0.10)	(14.50)	(14.58)	(0.23)
Observations	29,478	58,412	87,890	6,117	12,129	18,246

Note: The sample of variables only includes not used in matching, or without exact matching. For each variable in this table, we perform T-test at the quaarter before the matched date of branch closure. Credit variables are in euro thousands. Short term credit represents outstanding credit with initial duration below one year. Duration variables in months. Urban equals one for branches located in cities > 50,000 inhab., or in communes adjacent to cities > 100,000 inhab. Treated borrowers here only experience branch closures independently of any merger or sale of their banking group.

Table 4 - DiD of branch closure on the amount of credit

Dep.var: log(totfirm)	(1)	(2)	(3)	(4)	(5)	(6)
PostC	0.029***	0.036***	0.012**	0.030***	0.036***	0.016***
	(0.006)	(0.006)	(0.005)	(0.005)	(0.005)	(0.005)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Quarter Effects	Yes	Yes	Yes			
Quarter x Cohort FE				Yes	Yes	Yes
Branch Controls		Yes	Yes		Yes	Yes
Main Bank FE			Yes			Yes
R^2	0.85	0.85	0.89	0.91	0.92	0.94
Observations	1,207,041	1,205,442	1,205,432	1,196,872	1,195,179	1,195,169

Standard errors in parentheses
* $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

Note: Estimation of Eq.(2).
Branch controls variables are weighted by the proportion of firm's credit hosted by each branch, and they are set at the pre-treatment quarter for quarters after the closure. include Herfindahl-Hirschman index at the town level, the number of corporate borrowers in the branch, the number of branches from the same bank in town, and the number of French states (*rÃ©gions*) where the bank group is present.

Table 5 - Long-term DiD of branch closure on the amount of credit

Dep.var: log(totfirm)	(1)	(2)	(3)	(4)
PostC	0.062***	0.058***	0.057***	0.053***
	(0.011)	(0.012)	(0.012)	(0.012)
Both controls present (at both dates)			Yes	Yes
Branch controls		Yes		Yes
R^2	0.01	0.04	0.01	0.04
Observations	86,496	86,412	79,800	79,720

Standard errors in parentheses
* $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

Note: Estimation of Eq.(2), keeping only the matching date (three months before closure), and the date 2 years after. In the specifications where both controls may not be present at both dates, a single control firm is at least present within the cohort at both dates.

Table 6 - DiD of branch closure on the amount of each credit type

Dep.var: log(totfirm)	Short term	Long term	Drawn	Undrawn
PostC	-0.003	-0.000	0.018**	0.098***
	(0.018)	(0.017)	(0.008)	(0.021)
R^2	0.85	0.87	0.85	0.82
Observations	1,196,872	1,196,872	1,196,872	1,196,872

Standard errors in parentheses
* $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

Note: Estimation of Eq.(2), by type of credit.
Short term (resp., long term) credit includes credit with initial maturity lower than on year (resp., higher than one year).

Table 7 - Decomposition by usage of undrawn credit

Depvar:	Totfirm	Totdrawn	Short term	Long term
PostC	0.045***	0.053***	-0.058***	0.066***
	(0.006)	(0.010)	(0.025)	(0.022)
PostC x $I_{L.Nundrawn}$	-0.029***	-0.091***	0.139***	-0.168***
	(0.011)	(0.015)	(0.036)	(0.033)
R^2	0.91	0.85	0.85	0.87
Observations	1,196,872	1,196,872	1,196,872	1,196,872

Standard errors in parentheses

* $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

Note: Estimation of Eq.(2), including an interaction term $PostC \times I_{L.Nundrawn}$, with $I_{L.Nundrawn} = 1$ if the firm had no undrawn credit lines in the 7 quarters before its branch closure.

All estimations include firm fixed effects and cohort-quarter effects.

Table 8 - Heterogeneity analysis

Dep.var: log(totfirm)	No	Yes	No	Yes	No	Yes
Charact. I	Single		Main Branch closed		Risky	
	(1)	(2)	(3)	(4)	(5)	(6)
PostC	0.039***	0.026***	0.013	0.057***	0.037**	0.023
	(0.008)	(0.006)	(0.014)	(0.008)	(0.018)	(0.014)
R^2	0.90	0.90	0.87	0.91	0.92	0.94
Observations	729,296	467,576	245,574	543,480	162,936	152,789
Charact. II	In Group		Urban			
	(7)	(8)	(9)	(10)		
PostC	0.031***	0.043***	0.015**	0.048***		
	(0.006)	(0.014)	(0.007)	(0.008)		
R^2	0.90	0.90	0.91	0.91		
Observations	941,410	255,462	515,694	681,178		

Standard errors in parentheses
* $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

Note: Estimation of Eq.(2), keeping specific cohorts. All estimations include firm fixed effects and cohort-quarter effects.

Table 9 - Robustness checks

	(1)	(2)	(3)	(4)	(5)
	Banque x time	Indus x time	Drop treated if:		
Dep.var: log(totfirm)	x date FE	x date FE	multi firm-banks	2M+	MidCaps
PostC	0.021***	0.031***	0.033***	0.024***	0.029***
	(0.005)	(0.006)	(0.006)	(0.006)	(0.005)
R^2	0.90	0.85	0.91	0.88	0.91
Observations	1,196,755	1,207,033	1,000,082	1,043,646	1,184,782

Standard errors in parentheses

* $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

Note: Estimation of Eq.(2). All estimations include firm fixed effects and cohort-quarter effects.

Table 10 - Supply-side effect

Dep.var:	logtotfirm	logtotfirm	logtotfirm$_{LT}$
PostC	-0.007	-0.014	-0.029
	(0.011)	(0.014)	(0.026)
Branch Controls		Yes	
R^2	0.92	0.92	0.93
Observations	696,660	667,401	37,290

Standard errors in parentheses
* $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

Note: Estimation of Eq.(4). $logtotfirm_{LT}$ is the amount of credit of a borrower in each bank a quarter before its branch closes or 2 years after.

Table 11 - Heterogeneity analysis, Supply-side effects

Dep.var: log(totfirm)	No	Yes	No	Yes	No	Yes
Charact. I	Single		Main Branch closed		Risky	
PostC	-0.008	0.026	-0.017	-0.000	0.029	-0.042*
	(0.011)	(0.056)	(0.017)	(0.015)	(0.029)	(0.024)
R^2	0.92	0.96	0.95	0.90	0.91	0.90
Observations	676,400	20,260	181,402	504,232	219,635	188,809
Charact. II	In Group		Urban		Borrow previous year	
PostC	-0.024**	-0.007	-0.001	-0.011	-0.016	-0.001
	(0.012)	(0.011)	(0.016)	(0.015)	(0.015)	(0.017)
R^2	0.94	0.92	0.93	0.92	0.93	0.90
Observations	385,561	696,660	185,273	511,387	346,650	336,927

Standard errors in parentheses

* $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

Note: Estimation of Eq.(4), Heterogeneity analysis. All estimations include firm fixed effects and cohort-quarter effects.

Table 12 - Local credit competition

Type of bank	SameB	SameB	OtherB	OtherB	All	All
Rural		Yes		Yes		Yes
Dep.var: log(totfirm)	Same Town as closed branch					
PostC	0.004	0.009	0.054***	0.033***	0.051***	0.032***
	(0.008)	(0.009)	(0.008)	(0.010)	(0.008)	(0.010)
PostC × local	0.043***	0.012	-0.050***	-0.035***	-0.041***	-0.034***
	(0.010)	(0.013)	(0.010)	(0.013)	(0.011)	(0.013)
R^2	0.91	0.91	0.91	0.91	0.91	0.91
Observations	1,196,872	515,694	1,196,872	515,694	1,196,872	515,694
	Same Town + adjacent towns as closed branch					
PostC	0.011	0.008	0.057***	0.040***	0.057***	0.025**
	(0.007)	(0.009)	(0.008)	(0.011)	(0.008)	(0.010)
PostC × local	0.035***	0.014	-0.053***	-0.043***	-0.053***	-0.019
	(0.010)	(0.013)	(0.011)	(0.013)	(0.010)	(0.013)
R^2	0.91	0.91	0.91	0.91	0.91	0.91
Observations	1,196,872	515,694	1,196,872	515,694	1,196,872	515,694

Standard errors in parentheses

* $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

Note: Variables defined excluding the closed branch itself. Number of branches are computed at the firm level, such that they represent the average number of branches in the neighborhood of the each branch in relationship with the firm, weighed by the proportion of credit of the firm hosted by each branch. Urban equals one for branches located in cities > 50,000 inhab., or in communes adjacent to cities > 100,000 inhab.

SameB: number of local branches of the banking group of the closed branch minus 1

OtherB: number of local branches minus 1, and except the branches of the banking group of the closed branch

All: number of local branches minus 1 (except the closed branch)

local = 1 if the borrower has less local branches (of the bank of the closed branch, of other banks, of all banks) than 50% of the other borrowers considered in the estimation.

8 Appendix - Figures

Figure 1a

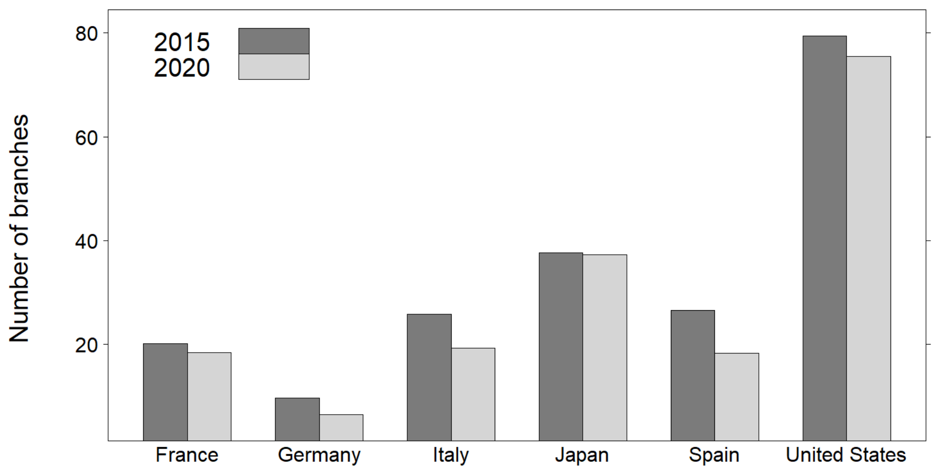
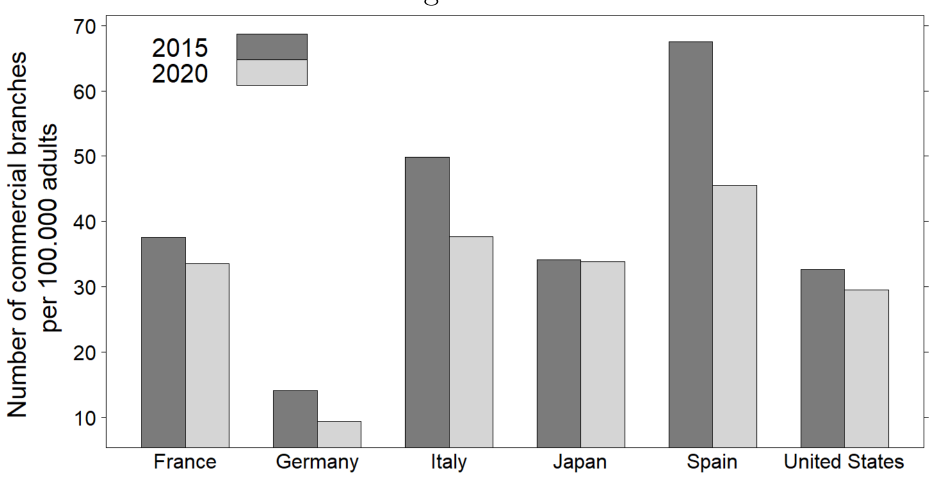
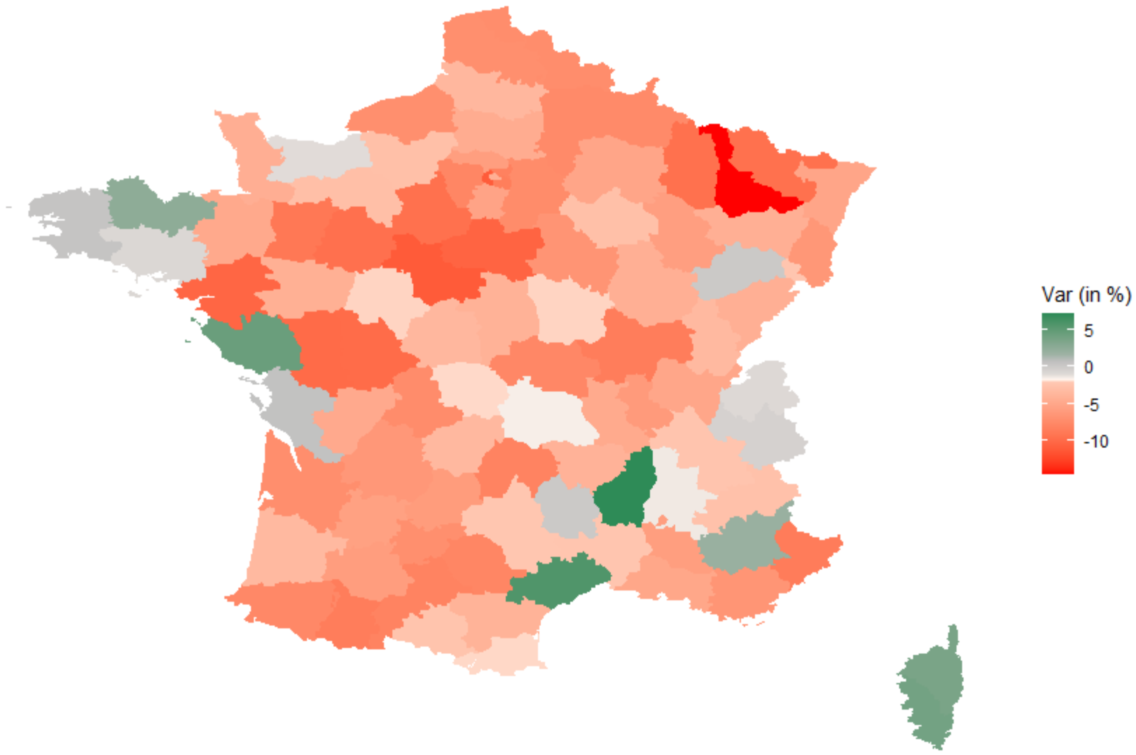


Figure 1b



Note: Number of branches from commercial banks (Figure 1a) and number of branches from commercial banks per 100.000 adults (Figure 1b). This excludes credit unions and cooperatives. Source: IMF, Financial Access Survey.

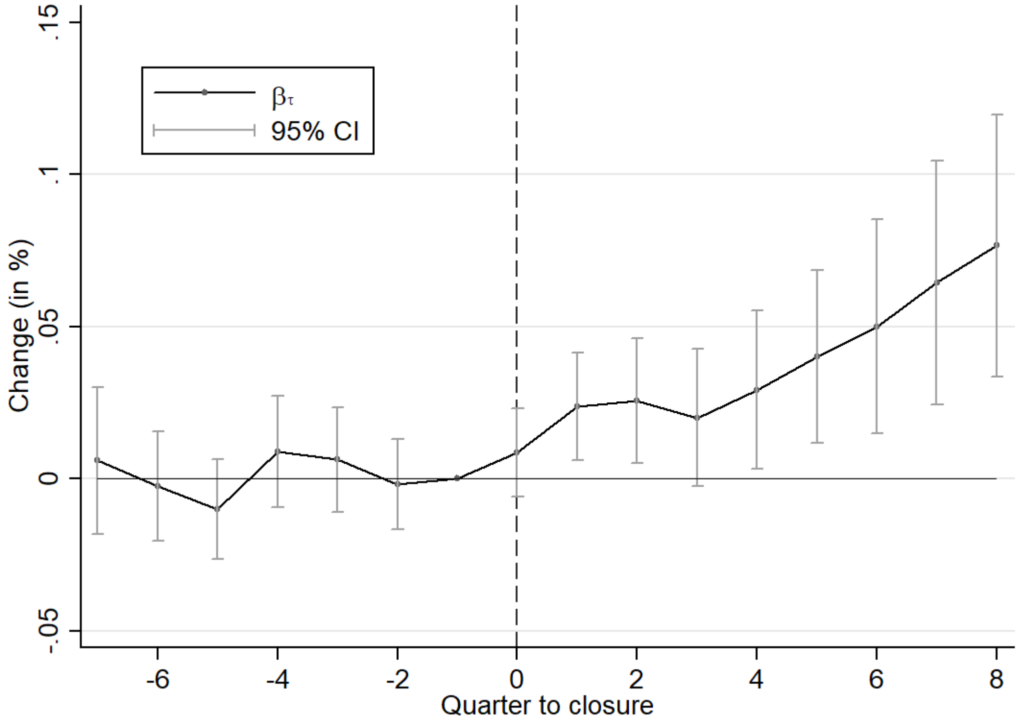
Figure 2 - Variation in the number of branches in France



Note: Variation in the number of branches in metropolitan France (Corsica included) between 2015 Q1 - 2020 Q1, per county (dÃ©partement). We only count branches which granted credit to firms or public administration, such that they appear in the Credit Registry.

Figure 4 - Branch closure effect on total credit amount - Restricted sample

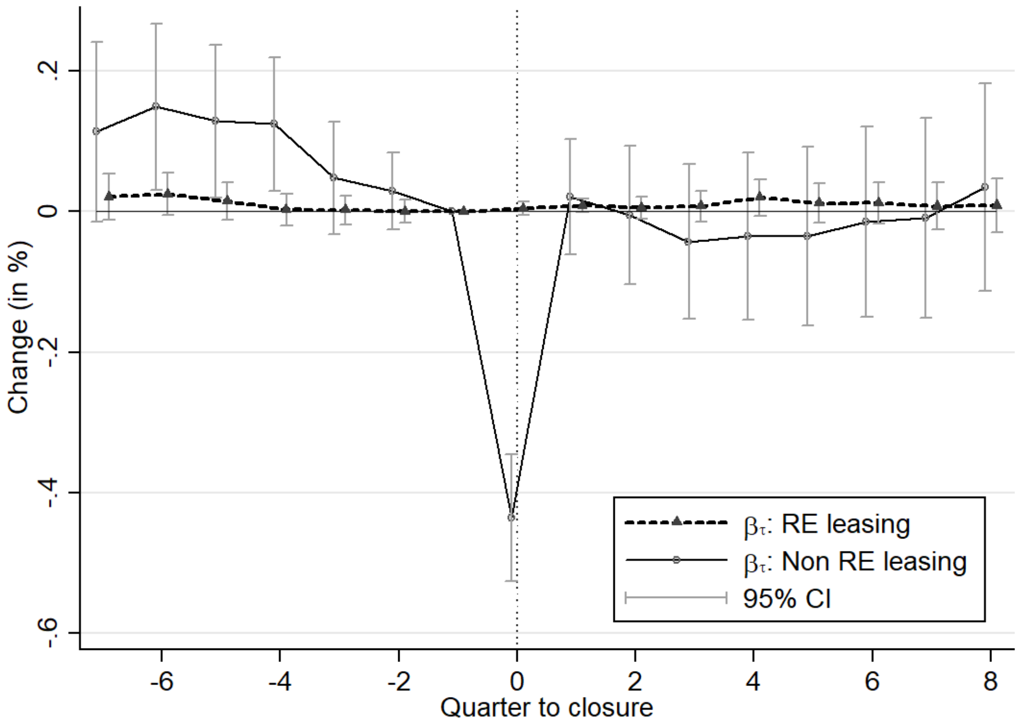
Figure 2.3:



Note: Estimation of Eq.(1), after additional matching within cohort, on total credit amount at the quarter before the date of closure

Figure 5 - Bank-level effect of the merger on leasing credit amount

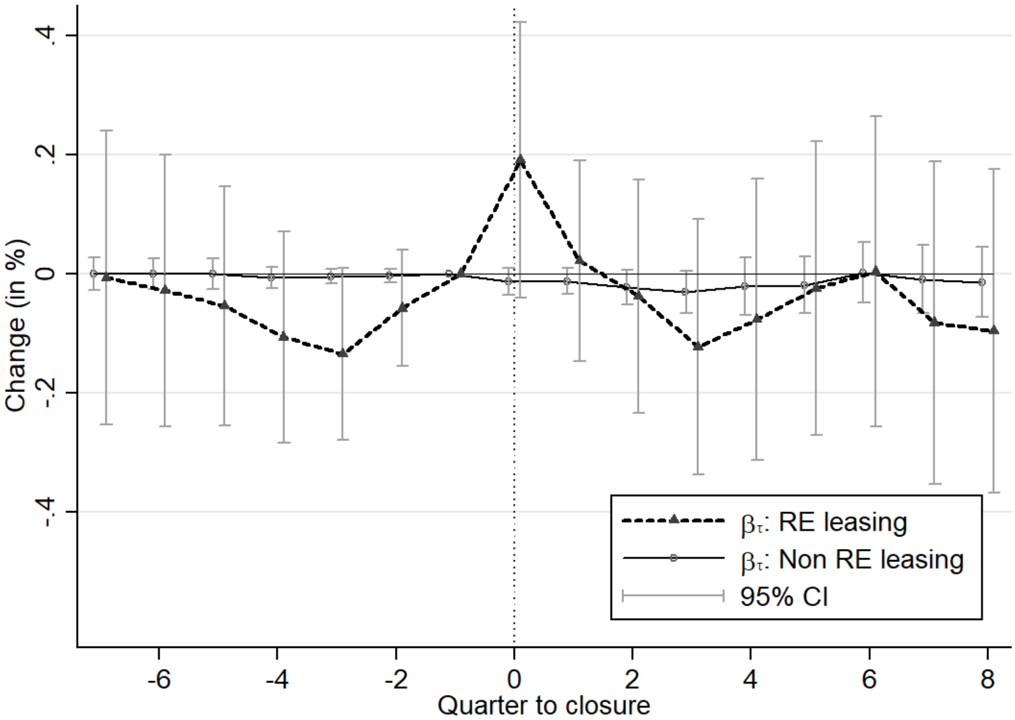
Figure 2.4:



Note: Estimation of Eq.(1) for Real-Estate leasing and non Real-Estate (i.e., movable-property) leasing, with control firms matched with treated firms based on all matching variables in Table 3a, except bank.

Figure 6 - Branch-level effect of the merger on leasing credit amount

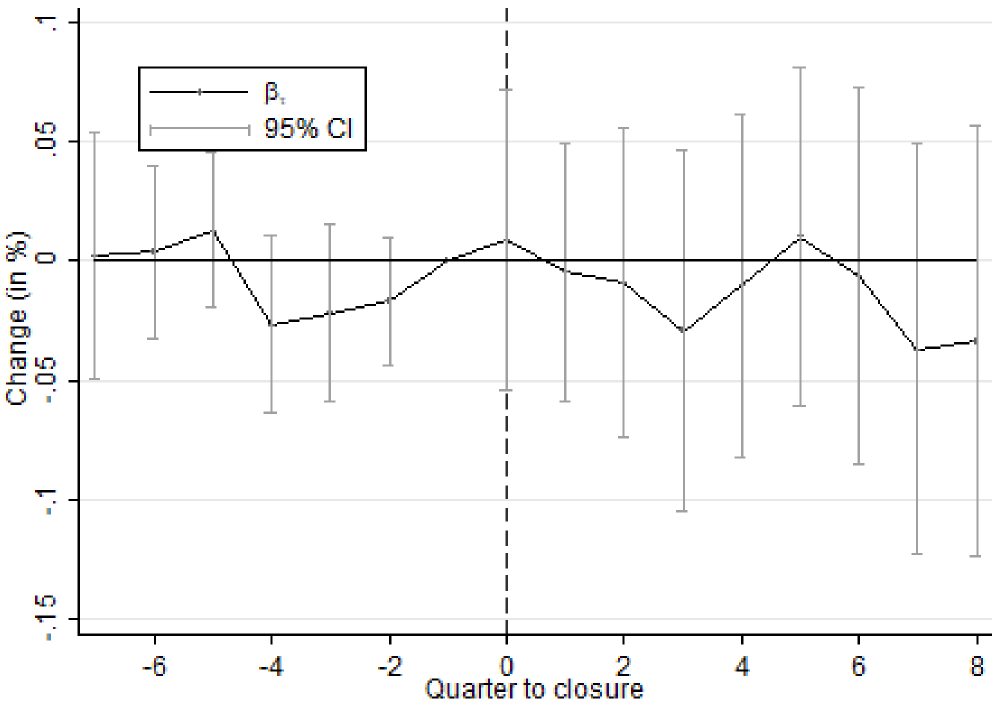
Figure 2.5:



Note: Estimation of Eq.(1) for Real-Estate leasing and non Real-Estate (i.e., movable-property) leasing, with control firms matched with treated firms based on all matching variables in Table 3a, including an exact matching on the merged bank.

Figure 7 - Branch-level effect of the merger on total credit

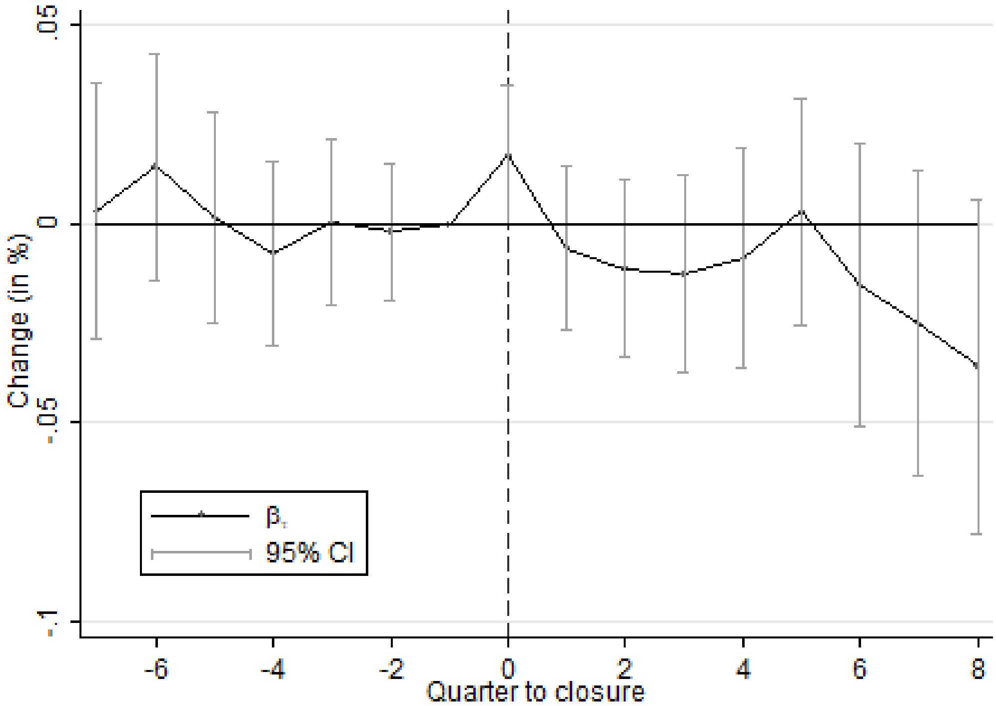
Figure 2.6:



Note: Estimation of Eq.(1) for total credit amount, with control firms matched with treated firms based on all matching variables in Table 3a, including an exact matching on the merged bank.

Figure 8 - Supply-side effects of branch closures

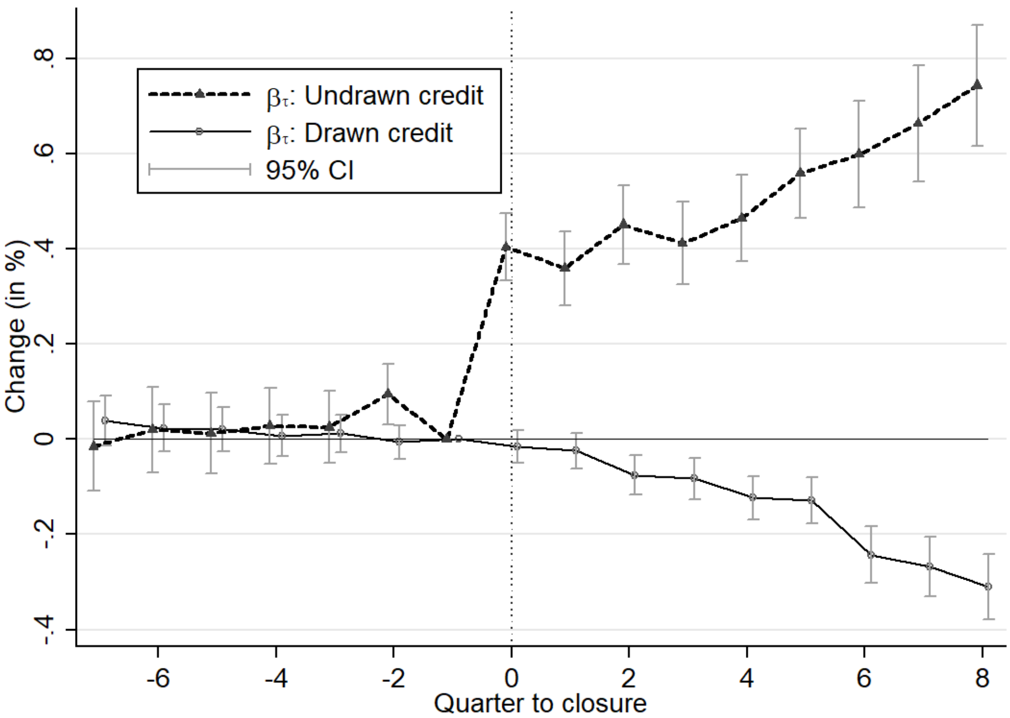
Figure 2.7:



Note: Estimation of Eq.(3) for total amount of credit.

Figure 9 - Supply-side effects of branch closures on the amounts of drawn and undrawn credit

Figure 2.8:



Note: Estimation of Eq.(3) for the amounts of drawn and undrawn credit.

Cyber Security and Cloud Outsourcing of Payments

Cyber Security and Cloud Outsourcing of Payments

N. Ciet & M. Verdier

Abstract

We study the incentives of competing banks to outsource their payment services to a common infrastructure, managed by a private third-party provider (TPP). The TPP provider stores depositors' information in the cloud and offers compatibility services, but is exposed to cyber risk. In the first-best benchmark, the regulator chooses to build a common payment infrastructure when the marginal social benefits are higher than the marginal social costs, and chooses the welfare-maximizing levels of security investment for all players. If the market is unregulated, without cyber risk, banks outsource excessively to the TPP compared to the first-best because network effects soften competition for deposits. However, we show that cyber risk and the costs of security may reduce banks' incentives to join the third-party infrastructure, which may result in an inefficiently low level of interoperability of their payment systems. We examine how the liability regime for cyber incidents may improve the players' investment in security. We show that increasing the TPP's liability towards depositors has a higher impact on payment system security than increasing its liability towards banks. We discuss how several regulatory options impact the security and compatibility of banks' payment systems: supervision of outsourcing agreements, shared responsibility model, public provision of payment services.

Keywords: payment systems, banks, cyber risk, cloud outsourcing, financial stability, compatibility, critical infrastructure
JEL Codes: E42, E58, G21, L51, O31.

1 Introduction

For decades, banks have outsourced the management of payment services to third-party providers. With the recent development of digital innovations in payments, the importance of cloud-based third-party providers in the banking sector has been growing rapidly.[1] According to the Financial Stability Board (2019), cloud computing is defined as an innovation that allows for the use of an online network of hosting processors, so as to increase the scale and flexibility of computing capacity.[2] Regulators are concerned that the outsourcing of payment systems to third-party providers could pose new risks for the security of retail banking activities and financial stability. For example, in 2022, the European Commission has reached a provisional agreement on a Digital Operational Resilience Act for financial services, which designs a regulation of Critical Third-Party Providers, including cloud service providers.[3]

In this paper, we are interested in understanding the optimal architecture of a retail payment system in the presence of cyber risk. We analyze how the liability regime for cyber incidents impacts banks' incentives to outsource their payment services to a cloud-based third-party provider, and the level of security of their payment systems. We obtain the following results. Without cyber risk, banks tend to outsource excessively their payment systems compared to the first-best because of network effects. However, the presence of cyber risk implies that banks may sometimes choose not to outsource enough their payment services when depositors benefit from interoperability.

Banks' partnerships with cloud service providers for payments may entail several benefits that can be ultimately passed on the depositors, such as the ability to deliver up-to-date services without supporting important innovation and storage costs.[4] In addition, the technical solutions offered by cloud service providers are often standardized and may scale-up rapidly. This implies that competing banks may easily rely on compatible solutions. In payments, banks often rely on a third-party cloud-based infrastructure (either privately or publicly managed) to develop interoperable payment solutions. For example, in the United-States, the private service provider Modo offers a platform that

[1] A study by the International Data Corporation (2018) shows that banks' spending on public cloud services has been growing at a rate of 23 percent per year over the last five years. In 2020 only, major partnerships of banks with cloud companies include Deutsche Bank with Google Cloud, Standard Chartered with Microsoft, and Bank of America with IBM.

[2] Cloud services model can be deployed either through a public cloud on the Internet, or by a private cloud that is only accessible by a single organization, or by a combination of the two.

[3] The latter would be supervised by one of the European Supervisory Authorities, who would have the power to request information, conduct inspections, issue recommendations, and impose fines in certain circumstances.

[4] Banks are able to deliver better mobile banking experiences or to use AI to make personalized recommendations of services to their clients, (see Lam and Seifert, 2021).

enables bank to achieve technical interoperability.[5]

Yet, the use of third-party service providers in banking generates new concerns for regulators.[6] For example, in December 2021, a five-hour outage of Amazon Web Service (AWS) impacted the access of consumers to many services, including banks' call centers and websites. In addition, banks migrate sensitive data outside their IT systems when they join the cloud, which increases the risks of data breaches. In 2019, 106 million credit card applications of Capital One Financial have been stolen from the AWS. Ongoing civil lawsuit against both AWS and Capital One suggest Capital One failed to implement security procedures available on its cloud platform (Covert, 2021).[7] Supervisors insist that banks are responsible for monitoring their service providers, while third-party companies have started to face transparency requirements towards their clients.[8] Several Central Banks have expressed the concern that the outsourcing of banking services to common third-party providers could increase the cyber risks in the financial sector (e.g., the Financial System Review of the Central Bank of Canada, 2019, the Reserve Bank of New Zealand, 2020, in a consultation paper).[9] On the other hand, cloud service providers contend that their services improve the security and the reliance of their payment systems.[10]

The presence of cloud service providers in the banking industry is related to the broader debate on public intervention in payment systems. Should the government build a common infrastructure to maximize the benefits of inter-operability (as is the case in Brazil with Pix or in India with UPI).[11] If not, how should the government design the regulatory framework to maximize the surplus of depositors, while ensuring that firms invest in the security of their payment systems? Is there an excessive use or an under provision of third-party services when banks are free to decide whether or not to join a common infrastructure, in the presence of cyber risks?

We build a model to analyze banks' incentives to join a common payment infrastructure managed by a private operator (the cloud service provider) in the presence of cyber risk. The cloud service provider offers to banks two different services: storage capacity and a

[5] https://modopayments.com/wp-content/docs/Modo-Overview-eBook.pdf

[6] In 2021, the Federal Reserve, the FDIC and the OCC launched a first interagency guidance to financial institutions related to their third-party relationships (see Federal Reserve System, 2021)

[7] The bank supervisor (the Office of the Comptroller of the Currency) found the bank liable of poor risk assessment when considering its cloud migration, as well as insufficient safeguards practices afterwards.

[8] US banking agencies introduced in 2022 customer notification requirements for a broad scope of third party service providers to banks. The equivalent measure in Europe is the DORA regulation.

[9] See the financial system review of the Bank of Canada (2019), the consultation paper of the Reserve Bank of New Zealand (2020) on cyber resilience.

[10] See the response of AWS to the consultation Reserve Bank of New Zealand.

[11] See D'Sliva et al., 2019.

payment app. There is a fee for each service. Banks compete in the downstream market of deposits on the Hotelling line and offer payment services to their consumers, which quality depends on the security of their payment systems. If the banks' depositors are equipped with the same payment app, they are able to send payments to one another. Some depositors are naive, while other are sophisticated and choose their banks according to the level of risk of its payment system. Since banks are unable to price discriminate between consumers, the price of deposits reflects banks' horizontal differentiation on the Hotelling line and banks' vertical differentiation in terms of payment system security.

Banks decide whether or not to join the cloud by comparing their benefits and costs of outsourcing their payment services. On the one hand, if both banks join the cloud and become interoperable, their depositors may enjoy the benefits of network effects. On the other hand, the security of their payment system changes and depends on the cloud service provider's investment. Banks also lose the benefits of security differentiation, which they obtain if they compete with independent payment solutions. Two additional inefficiencies may arise when banks join the cloud. First, if there a cyber incident, banks and depositors may incur higher losses. Second, the cloud service provider may under-report cyber incidents, which reduces the banks' and the depositors' ability to claim compensation. When there is a cyber incident, the liability regime allocates the total loss between the cloud service provider, the banks and the depositors. Our framework enables us to study how the liability regime impacts banks' incentives to outsource their payment services to the cloud service provider, and firms' investment incentives.

We start by analyzing the welfare-maximizing levels of security investments and the minimum value of the network effects such that the use of the cloud increases social welfare. If the social planner can choose the welfare-maximizing level of information disclosure, he prefers that the cloud service provider does not hide any information from the banks and the depositors. We show that the welfare-maximizing level of security of the payment system is higher if both banks join the cloud (than if they remain independent) if and only if the marginal benefits of delegating the investments in security to a third-party provider exceed the marginal costs. This happens if the cloud service provider incurs a sufficiently low cost of investing in cyber security, compared to the banks. For example, if there are no additional losses with cloud outsourcing, and if banks do not contribute to payment system security, cloud outsourcing increases the level of security of the payment system if the investment cost of the cloud service provider is lower than the sum of the banks' investment costs. This is due to the fact that cloud outsourcing generates efficiency gains by avoiding an inefficient duplication of investment costs. However, these efficiency gains may be offset by higher losses when a cyber incident occurs and higher costs of security. It follows that cloud outsourcing may not always increase payment system security. The outsourcing decision benefits the society if and only if the marginal benefits of interoperability are sufficiently high with respect to the potential marginal costs in terms of security.

Then, we analyze the game in which banks decide whether or not to join the cloud after investing in payment system security. The cloud service provider commits to offer a given level of investment in payment system security and chooses the access and compatibility fees that banks need to pay when they outsource their payment systems. At the last stage of the game, if a cyber incident occurs, the cloud service provider does not disclose it perfectly to the banks, to avoid becoming liable. This moral hazard issue generates some benefits and some costs for banks. On the one hand, if a cyber incident is not discovered by anyone, banks avoid compensating their depositors, which reduces their respective marginal cost. On the other hand, the cloud service provider's under-provision of information increases the amount of the losses when a cyber incident occurs. This implies that banks expect to incur higher losses when they decide to join the cloud. Banks trade off between relying on the cloud's infrastructure to increase the compatibility of their payment systems and remaining independent to enjoy the benefits of security differentiation. If banks choose different levels of investments in cyber security, one of them is riskier than the other. Depending on how cloud outsourcing impacts the expected losses, either the riskiest bank or its competitor has the highest willingness-to-pay for outsourcing services. We show that if the cloud service provider serves both banks, it charges an access fee that is equal to the lowest-willingness to pay for outsourcing services. However, the cloud service provider may also prefer to serve only one bank and extract the surplus of the bank that has the highest willingness-to-pay for outsourcing services. We show that in a symmetric equilibrium, both banks outsource their payment services if the cloud service provider earns a positive profit, and they both remain independent otherwise. Even if an asymmetric equilibrium does not exist in our setting, the possibility that a bank may deviate from the situation in which both banks join the cloud to enjoy the benefits of a higher security differentiation constrains the cloud service provider's pricing strategy.

Unlike the conventional wisdom, which often assumes that banks tend to outsource excessively their payment services to the cloud, we show that banks may sometimes choose not to outsource enough to the cloud service provider, with respect to the welfare-maximizing situation. We identify the market conditions such that banks under-outsource their payment services (resp., over-outsource). The banks' bias towards excessive outsourcing in caused by network effects in our setting and it is similar to the well-known results of the literature (see Foros and Hansen, 2001). Choosing higher levels of compatibility enables firms to soften competition in the next stages. However, we show that the presence of cyber risk may offset banks' incentives to outsource excessively and may even imply that banks sometimes do not outsource enough their payment systems with respect to the social optimum. This result is caused by several distortions with respect to the first-best. The vertical structure of the market adds several layers of inefficiencies caused by the timing of the investment and pricing decisions and the presence of moral hazard. Some effects reinforce the bias towards excessive outsourcing caused by network externalities, while other may compensate for it, and even reverse it, such that banks may sometimes under-outsource their payment services.

The vertical market structure implies the following distortions. First, the cloud service provider chooses its prices after banks choose their investments in security. This implies that it does not internalize the impact of its pricing strategy on banks' investment incentives. Because of this timing, the cloud service provider may under-estimate banks' rents of outsourcing, and offer its services too rarely compared to the first-best. This effect weakens the bias towards excessive outsourcing. Second, banks' investment incentives are distorted by the presence of moral hazard. However, in our paper, the effect of moral hazard on banks' investment in cyber security is ambiguous. On the one hand, banks have incentives to over-invest to protect themselves from the additional damage caused by under-reporting of cyber incidents. On the other hand, banks also benefit from the under-reporting of cyber incidents, as this enables them to avoid becoming liable towards their depositors. Thus, the moral hazard effect may either reinforce or weaken the bias towards excessive outsourcing caused by network externalities. Third, the cloud service provider does not internalize the impact of banks' expected damage on competition for depositors. In addition, neither the banks nor the cloud service provider internalize the expected losses incurred by the naive depositors. We conclude the paper by analyzing how the liability regime for cyber incidents impacts payment system security and banks' outsourcing decisions.

The rest of the paper is organized as follows. In Section 2, we survey the literature that is related to our work. In Section 3, we present the model and the assumptions. In Section 4, we present the first-best benchmark, in which the social planner chooses how much to invest in cyber security, how much to disclose on cyber incidents, and decides whether or not it is socially optimal that banks share a common payment system. In Section 5, we solve for the game in which firms decide how much to invest in cyber security, and banks decide whether or not to join the cloud. We end this section by discussing the impact of various regulatory options on payment system security and interoperability. Finally, we conclude.

2 Related Literature

Our paper is connected to five strands of the literature: the research on investment in cyber security, the role of cyber security in payments, the literature studying product liability and product compatibility, respectively, and the literature on the optimal market structure in network industries.

We contribute to the emerging economic literature on investment in cyber security (see Anderson et al., 2009 for a survey). Our work is closely related to the research question of De Corniere and Taylor (2021), who study how both the liability regime for cyber incidents and firms' business model impact investments in cyber security. They compare firms' investment in security with price competition and with advertising-funded business models. As in their paper, we assume that a proportion of consumers is naive and study the optimal liability regime. In contrast to previous works, we compare a business model with outsourcing to a cloud service provider to independent security provision. Therefore, we are interested in analyzing in a vertical relationship model the optimal liability regime with and without outsourcing to a third-party. In the context of software provision, Lam (2016) shows that a regime with full liability is inefficient because it implies overinvestment in attack prevention and damage control. Our paper differs from this work, as we model competition between firms and the role of a third-party provider.

Our paper also complements the literature on cyber security in payments. In this strand of the literature, several research papers analyze the optimal design of payment solutions when financial intermediaries trade off between security and convenience (see Kahn and Roberds, 2008, Kahn, Rivadeneyra and Wong, 2020, and Chiu and Wong, 2022) or security and the intensity of data usage (Garratt and Schilling, 2022). In our paper, the convenience benefit for consumers depends on banks' decision to outsource their services to a third-party, because outsourcing increases compatibility. In Kahn, Rivadeneyra and Wong (2020), the banks' choice of a technology impacts the consumers' incentives to protect their password and split their funds between several accounts. In Chiu and Wong (2022), cyber security impacts a platform's choice between issuing cash and accepting tokens. Several papers analyze how the liability regime affects the investment incentives of intermediaries (Kahn, Rivadeneyra and Wong (2020), Creti and Verdier (2014)). We study shared responsibility between the cloud service provider, the banks and the consumers. By comparison, Kahn, Rivadeneyra and Wong (2020) consider the shared responsibility between the custodian of the funds and the consumers. Creti and Verdier (2014) analyze how the liability regime of a two-sided monopolistic payment platform impacts payment instrument pricing and consumer surplus. Garratt and Schilling (2022) study how the network pattern of data flows across firms affects the resiliency to various cyber risks (DDOS, leakage, corruption) and the incentives of firms to collect data. Unlike Garratt and Schilling (2022), we do not study banks' incentives to collect data and focus on the effect of cyber risk on security investments in a cloud-based business model.

Our work is also connected to the law and economics literature on product liability (see Daughety and Reinganum, 2013, for a survey). The novelty of our model consists in analyzing the optimal liability regime in a vertical relationship model with network effects. In a vertical relationship setting, Jacob and Lovat (2016) focus on the effect of the liability sharing rule on the ability of firms to pay for damages. In contrast to their paper, we study the consequences of the liability regime on downstream competition, as well as the effect of asymmetric information between firms on cyber security. The use of the upstream infrastructure offered by the cloud-service provider enables downstream firms to enjoy the benefits of compatibility, because end-users benefit from making transactions with a larger consumer base. To our knowledge, no theoretical paper has studied this specific issue.

Our work also contributes to the long-standing literature on product compatibility and interoperability of payment systems, surveyed by Bianci et al. (2022). We consider interoperability at the platform level, which refers to the extent to which the users of one payment system can make transactions with the users of another service provider. We analyze whether banks have incentives to move to the cloud if they enjoy higher benefits of compatibility when they outsource their payment services. Matutes and Padilla (1994) derive the conditions under which banks share their ATMs and find that sometimes total incompatibility may prevail. Unlike in Malueg and Schwartz (2006) who consider quantity competition and asymmetric firms, we consider symmetric banks with Hotelling competition as Doganoglu and Wright (2006). As in their papers, banks' incentives to make their services compatible depend on the degree of network effects. Doganoglu and Wright (2006) study how multi-homing affect private and social incentives for compatibility, whereas we consider only single-homing consumers. As in Malueg and Schwartz (2006), we find that banks prefer to outsource when the degree of network effects is sufficiently high. Massoud and Bernhardt (2002) develop a model to study why banks may use inefficient pricing schemes in compatible ATM networks. Unlike in their work, we are interested in the inefficiencies caused by the liability for cyber incidents.

We also contribute to a literature studying the optimal market structure in network industries, when one or several upstream providers of a network infrastructure offer their services to firms which compete in a downstream market (see Dogan, 2009). The upstream provider(s) may decide to invest in the quality of the interconnection offered to downstream firms. In our paper, the upstream firm is the cloud service provider, and the downstream firms are the banks, which compete for depositors. Our work follows a similar approach to this strand of the literature, because we analyze the impact of the market structure on firms' investment incentives in a network industry. However, we design a model that applies more specifically to the banking industry. Therefore, we depart from this literature in three directions. First, we do not analyze the optimal quality of the interconnection service, which is exogenous in our model. We consider instead that firms' investment in cyber security is endogenous. In addition, all firms (upstream and downstream) contribute to the security of the payment system. Therefore, the downstream firms (i.e., the banks) also exert an externality on the upstream firm (i.e., the cloud service provider) when they choose how much to invest in payment system security. Second, the cloud service provider's input is not essential to offer payment services to depositors. This explains our choice to leave aside the issue of a possible vertical integration between banks and the cloud service provider. We only compare two market structures, with and without the upstream provider. Third, we have chosen to simplify the analysis of the compatibility decision, by assuming that banks become either fully compatible or remain incompatible. Firms' decisions to be compatible have been studied extensively in the literature on networks, with the different assumption that firms may become partially compatible (e.g., in Foros and Hansen, 2001 or in Stadler, Trexler and Unsorg, 2022). Our assumption that firms may only become fully compatible is in line with our understanding of competition in the payments industry: depositors are either equipped with the same payment app or cannot send payments to each other. In addition, our results remain valid as long as the degree of interoperability is sufficiently high when both banks join the cloud.

Our work is also indirectly related to the literature analyzing co-investment and infrastructure sharing in network industries, in the presence of demand uncertainty (see Inderst and Peitz, 2012, Bourreau et al., 2018). However, this literature studies whether co-investment improves social welfare when an entrant competes with an incumbent, which invests in an upstream infrastructure. Unlike in this strand of the literature, we assume that the banks and the cloud service provider incur different costs of security and do not compete for depositors. In addition, we assume that joining a common third-party provider enables the banks to improve the interoperability of their payment systems.

So far, we have assumed that banks cannot become compatible without joining the cloud, which is an assumption that we would like to discuss further in the future of our work, by studying the case in which banks jointly manage the upstream infrastructure.[12] A strand of the literature analyzes how banks jointly manage payment systems by determining the interchange fee, which is paid by the merchant's bank to the consumer's bank each time a consumer pays by card (see Verdier, 2011 and Rochet, 2003 for surveys). However, this literature assumes that payment systems are already interoperable and does not analyze banks' incentives to rely on a common payment infrastructure when outsourcing payment services may generate both benefits and costs.

[12]This case differs from the vertical integration hypothesis, because banks compete in the downstream market of deposits. So far, we have not discussed this option, to highlight the fact that the cloud service provider has access to a different technology that reduces the cost of investments in cyber security.

3 Model

We build a model to study banks' incentives to outsource their payment services to a cloud service provider in the presence of cyber risk. There are two banks in our model and a monopolistic cloud service provider. When banks rely on cloud services, they may enjoy the benefits of a higher compatibility of their payment solutions. However, the security of their payment system also depends on the cloud service provider's investment. If a cyber incident occurs, depositors may incur losses that may be partially compensated by transfers from the payment service providers (i.e., the cloud service provider and the banks). The cloud service provider may not disclose all the information on cyber incidents, which may increase the amount of the losses.

Cloud outsourcing: Two banks A and B are located at the two extremes of a Hotelling line, and compete in prices and security to serve a mass 1 of consumers who open a bank account to make payments. Bank A is located at point 0 and bank B is located at point 1. The price of an account in bank $i \in \{A, B\}$ is denoted by p_i and the level of security of payment transactions in bank i is s_i.

In the market, there is a third-party provider of payment services that we call the cloud service provider C. The third-party provider does not compete with banks for deposits.[13] Banks may buy two different services from C, which invests an amount $s_c \geq 0$ in the security of its infrastructure. First, they may use its cloud-based infrastructure to store information on payment transactions by paying a per-depositor access fee f^a to C. Second, if both banks store their payment information in the cloud, they may use additional services offered by the cloud to reach compatibility. If both banks decide to be compatible, we assume that each bank pays to the cloud service provider a fixed compatibility fee f^c.[14] The compatibility fee can be interpreted as the price of a payment app that the cloud service provider sells to both banks to help them reach compatibility.[15] The value of a payment app for a given bank increases with the number of compatible depositors from

[13] In our setting, the cloud service provider is a firm that has access to a different technology for the management of cyber risk, while being able to offer services that reduce the cost of building interoperable payment solutions.

[14] In the literature on interchange fees, the merchant's bank pays the consumer's bank an interchange each time a merchant pays by card. Our model departs from this literature, because we consider that the payment system is not jointly owned by banks.

[15] In practice, there are different business models of payment system outsourcing (Grabowski, 2021). The cloud service provider may be a Banking-As-a-Service platform, which does not sell services directly to the consumers. It may sell a payments App directly to banks or connect banks and app providers (see for instance the website of Amazon Web Services for examples of the various add-on services offered by a cloud service providers). Alternatively, the cloud service provider may sell services directly to the depositors.

the other bank.[16]

With this vertical market structure, the cloud service provider is therefore an upstream provider of payment services, which quality depends on the infrastructure security, whereas banks compete in the downstream market of deposits.[17]

We will refer respectively to the index n for the subgame in which there is no cloud outsourcing, c for the subgame with cloud outsourcing for both banks, and o for the subgame with cloud outsourcing only by bank $i \in \{A, B\}$.

Security investments and prevention of cyber incidents: The probability h_i that a cyber incident occurs in the payment system of bank i depends on its investments $s_i \in (0, 1)$ in cyber security and the investments $s_c \in (0, 1)$ of the cloud service provider, respectively. We assume that that the total level of security of the payment system is a weighted average of the bank's investments and the cloud service provider's investment, in shares θ and $1-\theta$, respectively. Without cloud outsourcing, the cloud service provider's investments have no impact on the security of the bank's payment system, such that we have $\theta = 1$. With cloud outsourcing, we have $0 \leq \theta < 1$.

The probability h_i is a linear function of security investments, such that $h_i(s_i, s_c, \theta) = h - \sigma(\theta s_i + (1-\theta)s_c)$, where $h \in (0, 1)$ represents the (exogenous) vulnerability of the payment system to a cyber incident, and $\sigma > 0$ models the sensitivity of h_i to the security investments.[18] We assume that s_i and s_c belong to $(0, h/\sigma)$. In the rest of the analysis, we will denote by $h_i^n(s_i) \equiv h_i(s_i, s_c, 1)$ the probability that a cyber incident occurs without cloud outsourcing, and by $h_i^c(s_i, s_c) \equiv h_i(s_i, s_c, \theta)$ the probability that a cyber incident occurs if bank i relies on the cloud for its payment system.[19]

We assume that the banks and the cloud service provider incur quadratic costs functions for cyber security investments. Each bank $i = A, B$ incurs a cost $C_b(s_i) = k_b s_i^2/2$ of investing s_i in cyber security, and the cloud service provider incurs a cost $C_c(s_c) = k_c s_c^2/2$, where $k_b > 0$ and $k_c > 0$. Our modelling of a quadratic cost function for security investments implies that each bank's total marginal cost is linear in the level of risk h_i

[16]The storage and the compatibility services are one-way complements because the compatibility service is only available if banks decided to use the storage service.

[17]The cloud service provider cannot price discriminate between banks.

[18]The probability h may depend of macroeconomics factors, ranging from the geopolitical context to the intensity of sector rivalries, as well as the state of the technology regarding the identification of software flaws. The efficiency of cyber protection depends crucially on the proportion of proprietary software, the level of caution of end-users and employees, as well as the identification of known threats by white hats, software firms or local governments.

[19]Typically, the cloud service provider is responsible for the security of the cloud (hardware, software), while banks are responsible for data usage (encryption, resource allocation, outside software), patching, and access to data. The allocation of security resources is negotiated by the bank and the cloud service provider.

as in Daughety and Reinganum (1995). Without cloud outsourcing, each bank's marginal cost depends only on its investments in cyber security.[20] With cloud outsourcing, each bank's marginal cost becomes also dependent on the cloud service provider's investment in security, because h_i is a decreasing function of s_c. The higher the security of payment services in the cloud, the lower the bank's marginal cost. Therefore, the cloud exerts a positive externality on the banks when it decides to increase its security investments. This type of externality is common in the literature on vertical relationships (Segal, 1999). In addition the access fee and the compatibility fee impact the cloud service provider's investment incentives, as in the literature on access charges in networks (e.g., Valetti and Cambini, 2004).

Information disclosure on cyber incidents: One difficulty with the liability regime for cyber incidents is caused by the lack of incentives both for the banks and the cloud service provider to report cyber incidents to the depositors.[21] Such under-reporting of cyber incidents may prevent the depositors from undertaking the required actions to reduce their losses or even claim compensation. This specific aspect of cyber incidents is a source of concern for the financial supervisors and regulatory bodies (see for instance the reports by the European Banking Authority, 2019, and the UK House of Commons, 2019).

Banks' incentives to report cyber incidents to their depositors are arguably higher than that of a cloud service provider, because of reputation incentives created by long-term relationships and cross-selling of financial services. Banks are also regularly audited by the financial supervisor. By contrast, the latter may not have the mandate to supervise the cloud service provider, which is sometimes not even located in the same country.[22]

We denote the amount of information concealed by a bank and the cloud service provider from the other players by v_b and v_c, respectively. The total amount of information v concealed on the cyber incident depends on the sharing of security investments, that is, we have $v = \theta v_b + (1-\theta)v_c$.

In the main part of the paper, we assume that the cloud service provider does not have the incentives to disclose perfectly the information on cyber incidents to the other players, while banks are perfectly transparent. The amount of information hidden by the cloud service provider $v_c \in (\underline{v_c}, \overline{v_c})$ depends on its cost $K(v_c) = \kappa(v_c^2 - \underline{v_c}^2)/2$ of concealing

[20]We assume that the security investments of banks generate no spillovers on the overall level of protection of their rivals. Alternatively, if each banks' investment exerts linear spillovers on the overall level of protection of its rival equals $s_i + \sigma s_{-i}$, with spillovers $\sigma \in (0,1)$ from the security investments of the other bank $-i$, each bank invests only a proportion $1-\sigma$ of their investments absent spillovers, without altering our results.

[21]On a sample of 276 incidents between 2010 and 2015 occurring in various sectors, Amir et al. (2018) estimated that, on average, firms hid cyber-attacks if their investors perceive the probability of the attack to be below 40%.

[22]See the reports by Horvath et al. (2014) and Robinson et al. (2011) for justifications of the cloud service provider's lack of incentives to report cyber incidents.

information, with $K(\underline{v_c}) = 0$, $K'(v_c) > 0$ and $K''(v_c) > 0$.[23] Both banks conceal the same exogenous amount of information v_b, which we normalize to $v_b \equiv 0$. This implies that $v = (1 - \theta)v_c$.

If the cloud service provider does not disclose perfectly all the information on cyber incidents to the other players, the depositors and the banks may not claim compensation or find convincing evidence that a cyber incident occured (as in Daughety and Reinganum, 2005). Therefore, we assume that they are able to claim compensation with some positive probability $q(v) \in (0, 1)$, which is a decreasing convex function of v such that $q(0) = 1$, $q(1) \in (0, 1)$, $q'(v) \leq 0$ and $q''(v) \geq 0$ for all $v \in ((1-\theta)\underline{v_c}, (1-\theta)\overline{v_c})$.

The losses caused by cyber incidents: When there is perfect disclosure of information, each depositor incurs a loss $l_d > 0$, which corresponds either to a loss of funds or the monetary cost of a leakage of his personal data. Using data on cyber incidents in Canada, Chande and Yanchus (2019) show that the losses incurred by the depositors vary according to the type of the cyber incident.[24] A bank incurs a loss per depositor $l_b > 0$, corresponding to the costs of fixing its security system, its reputation costs, or even higher funding costs. The total loss per depositor is $l = l_d + l_b$.

If the information is not disclosed perfectly by the cloud service provider, the amount of the losses incurred by the banks and the depositors, respectively, is multiplied by a factor $\alpha(v)$ and increases with the amount of hidden information. If all information is disclosed, we have $v = 0$ and $\alpha(0) = 1$. We further assume that $\alpha((1-\theta)\underline{v_c}) = \underline{\alpha}$ and $\alpha((1-\theta)\overline{v_c}) = \overline{\alpha}$.

The liability regime for cyber incidents: We consider a regime with strict liability and discuss in the extension section other possible regulatory instruments.[25] Without cloud

[23] This simplification remains valid as long as the cost of disclosing cyber incidents is much higher for the cloud service provider than for the banks.

[24] However, estimating the losses caused by cyber incidents remains a difficult task. In Canada, of finance and insurance businesses suffering a cyber incident, only 29 per cent reported it to police, 21 per cent reported it to the Canadian Cyber Incident Response Centre, 17 per cent reported the incident to their regulator.

[25] We do not include in our discussion a comparison with the negligence rules, which would involve changing our model to include the role of regulatory audits. The sharing of the losses for cyber incidents may vary across jurisdictions and depends on the liability regime. If banks do not outsource their services to the cloud, there is evidence that banks may be held liable for the cyber incidents that affect their depositors (e.g., in the United-States, Ocean Bank versus Patco Construction Company, the case of Comerica Inc. versus Mich. Experi-Metal). In the US, litigation follows almost all publicly disclosed breaches (Southwell et al., 2017). If banks outsource their services to the cloud, several jurisdictions make a distinction between the user of the service, the data owner (the bank) and the data holder (a cloud service provider providing hosting services). In the United-States (except HIPAA which places direct liability on a data holder), the data owner is liable for the losses resulting from a data breach, even if the security failures result from insufficient investment from the data holder (cloud provider).

outsourcing, the liability system defines the amount of compensation $\eta_d \in (0, l_d)$ given by the bank to a depositor when a cyber incident occurs.[26] Therefore, the bank incurs a loss $l_d + \eta_d$ and each depositor incurs a loss $l_d - \eta_d$. In addition, with cloud outsourcing, the liability system defines the transfers γ_d and γ_b from the cloud service provider to the depositor and the bank, respectively. Such transfers are common in payment systems (e.g., Visa and MasterCard).[27] Therefore, following a cyber incident, if a bank joins the cloud, each depositor claims compensation with probability q and incurs a loss

$$L_d(v) = \alpha(v) l_d - q(v)(\eta_d + \gamma_d),$$

a bank incurs a loss

$$L_b(v) = \alpha(v) l_b + q(v)(\eta_d - \gamma_b),$$

and the cloud service provider incurs a loss

$$L_c(v) = l_c + q(v)(\gamma_d + \gamma_b) + K(v), \tag{3.1}$$

We include into L_c the additional cost K of not disclosing cyber incidents to the other players. Without loss of generality, we normalize the cloud service provider's specific loss to $l_c \equiv 0$.

The expressions of L_d and L_b encompass the case in which banks do not join the cloud, when $\gamma_b = \gamma_d = 0$, $z = 0$, $\theta = 1$ (full contribution of banks to security), $v = 0$ (perfect disclosure), $\alpha(0) = 1$ (no additional damage) and $q(0) = 1$ (perfect ability to claim compensation).

The total loss caused by a cyber incident is

$$L(v) = L_d(v) + L_b(v) + zL_c(v),$$

with $z = 1$ if a bank joins the cloud and $z = 0$ otherwise. Since $l = l_d + l_b$, the total loss is therefore

$$L(v) = \alpha(v) l + zK(v).$$

In the rest of the analysis, we will use the loss functions L_d, L_b, L_c and L indifferently for the subgames c, n or o.

The amount of hidden information from the cloud service provider impacts the expected losses incurred by the bank and the depositors as follows. The loss per depositor L_d is increasing with v. The bank's loss per depositor L_b is increasing with v if $\eta_d \leq \gamma_b$. Otherwise, if $\eta_d > \gamma_b$. the bank's loss per depositor varies non monotonically with v. On the one hand, the bank incurs a higher damage when a cyber incident is unreported, but on the other hand, its saves its liability costs towards its depositors.

[26] In a landmark cyber security case, the UK Financial Conduct Authority (FCA) has fined Tesco Personal Finance plc (Tesco Bank) £16,400,000 after a cyber attack exposed weaknesses in the design of its debit card business and affected 8,261 personal current accounts.

[27] The payment system Heartland had to compensate several banks after a security breach and it paid 60 million dollars of financial damages.

Depositors: Each depositor located on the Hotelling line derives a utility $u_0 > 0$ for the use of a bank account, expects to obtain an additional utility $\beta > 0$ per payment transaction, and incurs the transportation cost $t > 0$ when he travels to open an account either in bank A or B.

A proportion $\mu \in (0,1)$ of depositors take into account the level of security of the payment systems when they decide in which bank to open an account, the rest of depositors, in proportion $1-\mu$, are naive or do not care about security.[28] Banks do not observe the depositors' types.

A depositor makes a payment transaction with all depositors who can be reached with the payment solution delivered by his bank (i.e., the compatible depositors). The number of depositors who open an account in bank $i = A, B$ is N_i and the expected number of depositors is N_i^e.

The number of compatible depositors depends on the bank's decision to outsource its payment services to the cloud. In practice, when banks outsource their payment services to the cloud, this increases the degree of interoperability of their payment services, compared to the situation without cloud outsourcing. We capture this feature in our model by making the extreme assumption that banks' payment systems are perfectly interoperable with cloud outsourcing, whereas they remain fragmented without cloud outsourcing. Formally, we would obtain equivalent results with an additional parameter representing the degree of interoperability of payment solutions, as long as the degree of interoperability is higher with cloud outsourcing. Therefore, if both banks decide to use the compatibility service, each depositor is able to make a transaction with all depositors (the total mass 1 of depositors), whereas, if both banks are not compatible, their depositors expect to make transactions only with the depositors who have an account in the same bank (in share N_i^e for the depositors of bank i).

A naive depositor located at point x on the Hotelling line who opens an account in bank i and expects to make transactions with N_i^e depositors obtains the utility

$$u_i(x) = u_0 + \beta(z + (1-z)N_i^e) - tx_i - p_i, \tag{3.2}$$

where $x_i = x$ if $i = A$, and $x_i = 1 - x$ if $i = B$, $z = 1$ if banks' payment systems are compatible, and $z = 0$ if banks' payment systems are incompatible. A sophisticated depositor located at point x also takes into account the expected losses caused by cyber incidents $L_d(v)$ which occur with probability $h_i(s_i, s_c, \theta)$. Therefore, he obtains a utility

$$u_i(x) - h_i(s_i, s_c, \theta)L_d(v) \tag{3.3}$$

of opening an account in bank i, where $\theta = 1$ and $v = 0$ in case bank i does not join the cloud.

[28] We assume that security investments and depositor sophistication are non-verifiable, such that it is not possible to write contingent contracts contingent that depend on these variables.

Bank profits: Bank i's profit is the sum of the profits from deposits, less the costs of security investments and security incidents, and the potential fees paid to the cloud, if any. It is therefore given by

$$\pi_i = (p_i - h_i(s_i, s_c, \theta)L_b(v) - z_i f^a)N_i - z_i z_{-i} f^c - C_b(s_i), \tag{3.4}$$

where $\theta = 1$, $v = 0$, $z_i = 0$ if bank i does not outsource its payment services to the cloud, and $z_i = 1$ otherwise. If both banks' payment services are compatible ($z_i = z_{-i} = 1$), each bank pays the fixed compatibility fee f^c.

Cloud service provider profit: The cloud service provider's profit is the sum of the revenues from the access fee f^a, the compatibility fee f^c, if any, less the costs of security investments and security incidents. If the market is covered and banks' payment services are compatible, the cloud service provider makes a profit

$$\pi_C^c = 2f^c + (f^a - h_i^c L_c(v))N_i + (f^a - h_{-i}^c L_c(v))N_{-i} - C_c(s_c). \tag{3.5}$$

If only bank i joins the cloud, the cloud service provider makes a profit

$$\pi_C^o = (f^a - h_i(s_i, s_c, \theta)L_c(v))N_i - C_c(s_c). \tag{3.6}$$

Finally, if no bank joins the cloud, the cloud service provider does not make any profit.

Assumptions Finally, we formalize four additional assumptions:

- (A1): For all $v \in (0, (1-\theta)\overline{v_c})$, $t - \beta > k_b > 2h(L_d(v) + L_b(v)/3$. Assumption (A1) implies that banks' profits are concave in security investments and prices and that both banks make positive profits in equilibrium.
- (A2) $h \geq \sigma$. Assumption (A2) implies that if firms invest their maximum possible amount in cyber security ($s_c = s_b^i = 1$), they do not eliminate completely cyber risk.
- (A3): For all $v_c \in (\underline{v_c}, \overline{v_c})$, $L_c''(v_c) \geq 0$, with $L_c'(\underline{v_c}) < 0 < L_c'(\overline{v_c})$. Assumption (A3) is a necessary condition for the cloud service provider not to disclose either the minimum or the maximum level of information on cyber incidents to the other players.
- (A4) $k_c > \max(\theta\underline{\alpha}\sigma l, (1-\theta)\underline{\alpha}\sigma l)$ and $k_b > \sigma l/2$. Assumption (A4) implies that investment costs k_c and k_b are sufficiently high such that there is an interior solution when the regulator chooses the welfare-maximizing levels of investments in security.[29]

Timing of the game:

1. The cloud service provider decides on the amount s_c invested in the security of its infrastructure.

[29]The inequality $k_b > \sigma l/2$ is implied by (A1) and (A2).

2. Each bank $i \in \{A, B\}$ decides non cooperatively on its level of investment s_i in cyber security.
3. The cloud service provider sets an access fee f^a and a compatibility fee f^c. Each bank decides on whether or not to outsource its payment services and on whether or not to buy the compatibility service.
4. Banks compete for depositors by choosing their deposit prices p_i for $i \in \{A, B\}$, respectively.
5. A cyber incident occurs with probability $h_i(s_i, s_c, \theta)$ in the payment system of bank $i \in \{A, B\}$. If bank i outsourced its payment service, the cloud service provider decides on how much information v_c to hide on the cyber incident. The losses are split between the bank, the depositors and the cloud service provider according to the liability rules.

4 The welfare effects of cloud outsourcing:

In this section, we analyze a benchmark in which a social planer chooses the welfare-maximizing levels of investment in security and the optimal level of disclosure of cyber incidents. We examine the impact of cloud outsourcing on social welfare.

4.1 Welfare-maximizing security investments:

We compare the welfare-maximizing security investments if both banks decide to outsource their payment services to the cloud and if they do not. Social welfare is the sum of the depositors' surplus and the firms' profits less the transportation costs incurred by the depositors. We denote the social welfare by W^n when banks do no outsource, and by W^c when banks outsource and they are compatible. The social planner's objective is to maximize social welfare by choosing the level of security offered by each firm (the two banks, and the cloud service provider) and the level of reporting of cyber incidents.

Without cloud outsourcing, since banks have identical costs, the social planner chooses symmetric levels of security investments for both banks, such that their profit at the equilibrium of stage 4 does not depend on the level of security.[30] The social planner maximizes

$$W^n = \beta/2 - t/4 - h_i^n(s_i)l - k_b s_i^2. \tag{3.7}$$

The social planer chooses a level of security for each firm (bank and cloud service provider) such that the marginal benefits of a higher security for the society are equal to the marginal

[30] If the social planner chooses symmetric levels of investment in security for both banks, because increasing the level of security for bank i does not increase marginally bank k's profit.

costs. Thus, the welfare-maximizing level of investment in cyber security s_w^n equals

$$s_w^n = \frac{\sigma l}{2k_b}. \tag{3.8}$$

Banks' total cost of security investments is equal to $C_b^n = k_b(s_w^n)^2$.

If both banks outsource their payment services to the cloud, the social planner maximizes

$$W^c = \beta - t/4 - h_i^c(s_i, s_c)L(v) - k_b s_i^2 - k_c s_c^2/2. \tag{3.9}$$

Since the total loss L is increasing with v, the social planner prefers that the cloud service provider discloses the maximum amount of information on cyber incidents, that is, $v_c = \underline{v_c}$. Therefore, the welfare-maximizing level of banks' investment in cyber security equals

$$(s_w^c)^b = \theta \underline{\alpha} s_w^n,$$

and the welfare-maximizing level of cloud service provider's investment in cyber security equals

$$(s_w^c)^c = \frac{2k_b}{k_c}(1-\theta)\underline{\alpha} s_w^n.$$

Since a bank and the cloud service provider contribute respectively in share θ and $1-\theta$ to payment system security, with cloud outsourcing, the total security of the payment system is given by:

$$s_w^c = (\theta^2 + \frac{2k_b}{k_c}(1-\theta)^2)\underline{\alpha} s_w^n. \tag{3.10}$$

Finally, we denote by $\Delta s^b \equiv s_w^n - \theta(s_w^c)^b$ the difference in banks' welfare-maximizing contribution to payment system security without and with cloud outsourcing. We have

$$\Delta s^b = (1 - \theta^2 \underline{\alpha}) s_w^n.$$

The welfare-maximizing contributions of banks to payment system security differ with and without cloud outsourcing. The social planer chooses security investments such that the marginal benefits of a higher security are equal to the marginal costs. Cloud outsourcing multiplies the marginal benefits of banks' investments in security by a factor $\theta\underline{\alpha}$. First, banks' investments in security have a lower marginal impact on the probability that a cyber incident occurs, because banks only take on a marginal share θ of the security effort. Second, with cloud outsourcing, the minimum total loss equals $\underline{\alpha} l$. Therefore, banks' welfare-maximizing level of security increases if and only if $\theta\underline{\alpha} > 1$. Since banks take on a share θ of security investments, the welfare-maximizing contribution of banks to payment system security is higher with cloud outsourcing if and only if $\theta^2\underline{\alpha} > 1$.

In Proposition 1, we compare the welfare-maximizing level of security of the payment system with or without cloud outsourcing.

Proposition 11. The welfare-maximizing level of security is higher if both banks outsource their payment services to the cloud if either $\Delta s^b \leq 0$ or $\Delta s^b > 0$ and

$$k_c < k_s \equiv 2k_b \frac{(1-\theta)^2 \underline{\alpha}}{1-\theta^2 \underline{\alpha}}.$$

Proof. See Appendix 1. □

The presence of the cloud service provider is beneficial for the society if the marginal benefits of security investments implied by cloud outsourcing exceed the marginal costs. If banks' welfare-maximizing contributions to payment system security increase with cloud outsourcing, social welfare is always higher when both banks join the cloud. If banks' welfare-maximizing contributions to payment system security are reduced, the welfare-maximizing level of security is higher with cloud outsourcing if and only if the cloud service provider's contribution compensates for the banks' lower investment.

The cloud service provider contributes marginally to payment system security in share $(1-\theta)$ and it invests a share $(2k_b/k_c)(1-\theta)\underline{\alpha}$ of the welfare-maximizing security without cloud outsourcing. Therefore, the presence of the cloud service provider implies a marginal benefit for the society that is equal to $(2k_b/k_c)(1-\theta)^2\underline{\alpha}$, and a marginal cost $(1-\theta^2\underline{\alpha})$, which are expressed in share of the initial security without outsourcing, respectively. If the inequality of Proposition 1 holds, the marginal benefits implied by cloud outsourcing exceed the marginal costs.

In the special case in which banks neither contribute to the security of the payment system (i.e., $\theta = 0$), nor do they incur additional losses with cloud outsourcing (i.e., $\underline{\alpha} = 1$), the welfare-maximizing level of security is higher with cloud outsourcing if and only if $k_c < 2k_b$. Cloud outsourcing enables the social planer to avoid an inefficient duplication of security investments, because the cloud service provider's investments benefit both banks. Thus, without cloud outsourcing, reaching the same level of security in each bank requires spending twice the same amount, which is a source of inefficiency.

4.2 Welfare-maximizing outsourcing decisions:

An important issue is whether a regulator should decide to build an interoperable joint payment system when it can control security investments. In Proposition 2, we compare social welfare with and without cloud outsourcing. For this purpose, we denote by

$$\Delta L_w = (\underline{\alpha} h_c((s_w^c)^b, (s_w^c)^c) - h_n(s_w^n))l$$

the difference in the total expected loss with and without cloud outsourcing, respectively, and by

$$\Delta C_w = k_b(((s_w^c)^b)^2 - (s_w^n)^2) + \frac{k_c((s_w^c)^c)^2}{2}$$

the difference in the costs of payment system security with and without cloud outsourcing, respectively.

Proposition 12. Cloud outsourcing increases social welfare if and only if:

$$\beta > max(0, \beta_w),$$

with $\beta_w \equiv 2(\Delta L_w + \Delta C_w)$. If the costs of security investments incurred by the cloud service provider are sufficiently low, cloud outsourcing is beneficial for the society for any level $\beta > 0$ of network effects. Such a situation happens if and only if:

$$k_c < k_w \equiv k_s \frac{(1-\theta^2\underline{\alpha})C_b^n}{(1-\theta^2\underline{\alpha}^2)C_b^n + (\underline{\alpha}-1)hl} < k_s,$$

where $C_b^n = (\sigma l)^2/(4k_b)$ represents banks' cost of security if the social planer chooses a market structure without cloud outsourcing.

Proof. See Appendix 1. □

Cloud outsourcing reduces the cost of fragmentation of payment systems (see the BIS annual report, June 2022).[31] First, cloud outsourcing increases the welfare benefits of network effects by $\beta/2$, because banks' payment systems become compatible. With interoperable payment systems, a depositor is able to make a payment transaction with all other depositors (in share 1, which generates a benefit β for the society), whereas, he makes a transaction with only half of the depositors if banks' payment systems are fragmented (with a welfare benefit of $\beta/2$). Second, as explained in Proposition 1, cloud outsourcing avoids an inefficient duplication of security investments, which benefits the society if the cloud service provider's marginal cost of security is less than twice the banks' marginal cost of security.

At the same time, with welfare-maximizing investments, cloud outsourcing may not improve payment system security and also implies additional potential losses for banks and depositors. Even if the cloud service provider discloses perfectly cyber incidents, cloud outsourcing raises the additional maximal potential loss in case of a cyber incident by $(\underline{\alpha}-1)hl$ (with zero security investments). We have shown in Proposition 1 that with the welfare-maximizing levels of security investments, payment system security may be either higher or lower with cloud outsourcing than with independent banks. Therefore, cloud outsourcing may either improve or weaken payment system security. Even a higher level of payment system security may not be sufficient to compensate for the additional losses incurred by the banks and the depositors. In addition, the society benefits from a

[31]The BIS report of 2022 mentions the cost of fragmented payment systems for the economy and the welfare gains associated with interoperability. The report does not mention whether the infrastructure that manages the joint payment system is public or private (see e.g. on p.91).

more secure payment system, only if the welfare gains from a reduction of the expected loss compensate for the costs of security investments. Thus, even if a higher payment system security compensates for the costs of the additional losses, payment system security may also become more costly with cloud outsourcing. Therefore, cloud outsourcing improves social welfare only if the benefits of interoperability are sufficiently high with respect to the marginal net costs implied by cloud outsourcing. If cloud outsourcing lowers the total cost of cyber incidents, including security investments and expected losses, social welfare is always higher when both banks move to the cloud, whatever the level of network effects. This happens if the cloud service provider's marginal cost is sufficiently low (i.e., lower than k_w).

Note that if banks were free to choose to move to the cloud, while being constrained to choose the welfare-maximizing levels of investment in security (e.g., by a security standard), they would make inefficient decisions. Banks' incentives to outsource their services to the cloud do not coincide with the welfare-maximizing decision, because the latter do not take into account the impact of their outsourcing choice on the cloud service provider's investment incentives, nor on its expected loss.

5 Cyber security and bank competition:

In this section, we analyze banks' decisions to outsource their payment services to the cloud when they choose their investments in security non-cooperatively, and the cloud service provider is a private operator.

5.1 Stage 5: information disclosure on cyber incidents:

At the last stage of the game, if bank i joined the cloud, the cloud service provider observes whether a cyber incident has occurred with the depositors of bank i, and it chooses how much information to hide on the cyber incident. The cloud service provider maximizes its profit by minimizing its expected loss in case of incident $L_c(v)$, given in Eq.(3.1). If $\gamma_d + \gamma_b > 0$ and $\theta < 1$, the loss-minimizing level of information v_c^* equalizes the marginal benefit of avoiding to be liable for the cyber incident and the marginal cost of hidden information, that is we have

$$-(1-\theta)(\gamma_d + \gamma_b)q'(v^*) = \kappa v_c^*, \tag{3.11}$$

where $v^* = (1-\theta)v_c^*$. When the liability regime allocates a higher share of the losses to the cloud service provider, its incentives to disclose cyber incidents are reduced, because the latter prefers to avoid becoming liable. If the cloud service provider is not liable (i.e., if $\gamma_d + \gamma_b = 0$), it hides the minimum amount of information from the bank and depositors, that is, we have $v^* = (1-\theta)\underline{v_c}$.

If bank i does not join the cloud, this bank and its depositors are perfectly informed on cyber incidents. Therefore, the amount of information hidden to bank i and its depositors equals zv^*, where $z = 0$ for the bank that does not join the cloud, and $z = 1$ for its competitor if the latter joins the cloud.

5.2 Stage 4: competition for deposits:

We determine how banks price deposit services if they take symmetric outsourcing decisions (that is, in subgames n without cloud outsourcing and c with cloud outsourcing, respectively).

The deposit prices and bank profits:

We start by analyzing consumer demand for deposits. From Eqs.(3.2) and (3.3), a naive depositor obtains a utility $u_i(x)$ of opening an account in bank i, while a sophisticated depositor only obtains $u_i(x) - h_i L_d(zv^*)$ because he expects to face the loss $L_d(zv^*)$ with probability h_i. Given that only a proportion μ of depositors are sophisticated, the average expected utility of a depositor equals $u_i(x) - \mu h_i L_d(zv^*)$.

We denote by $\Delta h \equiv h_i - h_{-i}$ the degree of security differentiation between banks, with $\Delta h = \Delta h^n$ in the subgame where both banks remain independent and $\Delta h = \Delta h^c$ in the subgame where both banks join the cloud, respectively. At the equilibrium of stage 4, depositors' expectations of banks' market shares are fulfilled, and each bank $i \in \{A, B\}$ obtains a market share given by:

$$N_i = \frac{1}{2} + \frac{p_{-i} - p_i - \mu \Delta h L_d(zv^*)}{2(t - (1-z)\beta)}, \tag{3.12}$$

where $z = 1$ if both banks join the cloud and pay the compatibility fee, and $z = 0$ if they do not.[32]

The market share of bank i depends on the marginal cost asymmetries implied by security differentiation, which are internalized by sophisticated depositors (in proportion μ). Indeed, the latter incur different expected costs of cyber incidents according to their bank choice. In addition, the price sensitivity of consumer demand for deposits is increasing with network effects if payment systems are fragmented. Indeed, consumers anticipate that when a bank undercuts the price of its rival, the value of its payment services increases because of network effects. This effect does not exist if payment systems are interoperable. Therefore, interoperability softens competition for deposits.

[32] No bank corners the market if $N_i \in (0,1)$, which is equivalent to $p_i - p_{-i} + \mu \Delta h L_d(zv^*) \in (-t + (1-z)\beta, t - (1-z)\beta)$.

At the competition stage, each bank i chooses p_i to maximize its profit π_k given in Eq.(3.4). Solving for the first-order conditions of bank profit-maximization, at the equilibrium of stage 4, if banks take symmetric outsourcing decisions, the prices of deposits are given by

$$p_i^* = t + h_i L_b(v^*) + z f^a - (1-z)\beta - \frac{\Delta h}{3}\rho(zv^*), \tag{3.13}$$

where banks' marginal cost of cyber incidents, including the internalization of the sophisticated depositors' losses, is given by :

$$\rho(zv^*) = L_b(zv^*) + \mu L_d(zv^*).$$

The deposit prices chosen by banks at the equilibrium of stage 4 are similar to the standard Hotelling model with asymmetric marginal costs. A bank's marginal cost is the sum of the expected losses caused by cyber incidents $h_i L_b(zv^*)$, the access fee paid to the cloud service provider zf^a (if any when $z = 1$), net of the marginal benefit of network effects $(1-z)\beta$. The last term corresponds to the differentiation of banks' marginal costs if they choose different levels of security for their payment systems. The higher the magnitude of network effects, the higher the banks' incentives to decrease their prices if their payment systems are fragmented. Banks take into account the marginal benefits of attracting an additional depositor when they choose their prices, because they anticipate that this depositor will have a positive impact on the overall demand for deposits.

Replacing for p_i^* given by Eq.(3.13) in Eq.(3.4), the profit of bank i at the equilibrium of stage 4 is given by:

$$\pi_i(p_i^*, p_{-i}^*, f^c, f^a, s_i, s_{-i}) = \frac{(t - \beta(1-z) - (\Delta h)\rho(zv^*)/3)^2}{2(t-(1-z)\beta)} - zf^c - C_b(s_i). \tag{3.14}$$

There is full pass-through of banks' expected marginal costs to their depositors. Therefore, if banks take symmetric outsourcing decisions, the access fee has no impact on their profits.

The liability regime for cyber incidents and bank profits:

The liability regime impacts banks' marginal costs of cyber incidents, and therefore, their profits. Banks' marginal costs differ when they join the cloud and when they remain independent. Without cloud outsourcing ($z = 0$), a bank's marginal cost of cyber incidents, including internalization effects, is given by:

$$\rho(0) = l + (1-\mu)(\eta_d - l_d).$$

and with cloud outsourcing ($z = 1$), it is given by:

$$\rho(v^*) = \alpha(v^*)l + (1-\mu)(q(v^*)\eta_d - \alpha(v^*)l_d) - q(v^*)(\mu\gamma_d + \gamma_b), \tag{3.15}$$

If all depositors are sophisticated ($\mu = 1$), banks internalize perfectly the depositors' losses. Without cloud outsourcing, their marginal cost of cyber incidents is equal to the total loss $l = l_b + l_d$. The transfer that the bank gives to the depositors η_d is neutral, because the banks pass on their marginal cost to the depositors through higher deposit prices. If some depositors are naive ($\mu < 1$), banks internalize imperfectly the depositors' losses. Therefore, a higher transfer η_d increases their marginal cost.

With cloud outsourcing, if all depositors are sophisticated, banks also internalize perfectly the depositors' losses. Their marginal cost is equal to the total loss, less the total transfers received from the cloud service provider when a cyber incident is disclosed (i.e, $\alpha(v^*)l - q(v^*)(\gamma_d + \gamma_b)$). Since banks internalize the sophisticated depositors' losses, they also benefit from the transfer that the depositors receive from the cloud service provider (i.e., γ_d). If some depositors are naive, the banks internalize imperfectly the depositors' losses.

The cloud service provider's transfers to banks and depositors have a complex impact on banks' marginal costs. With an exogenous amount of hidden information, the transfers from the cloud service provider reduce banks' marginal costs. However, because of moral hazard, the cloud service provider hides more information when its liability is extended, which has an ambiguous impact on banks' marginal costs. Taking the derivative of ρ with respect to the amount of hidden information v gives:

$$\rho'(v) = \alpha'(v)(l_b + \mu l_d) + q'(v)(\eta_d(1 - \mu) - \mu\gamma_d - \gamma_b). \tag{3.16}$$

On the one hand, if the cloud service provider hides more information, banks' expected damage increases, which raises their marginal cost. On the other hand, this reduces the probability that banks have to compensate their depositors for cyber incidents when the latter are unable to claim compensation. This second effect lowers their marginal cost.

To understand better the role of moral hazard and depositor sophistication in our setting, it is useful to consider examples:

- **High proportion of sophistication of depositors:**
  If the proportion of sophisticated depositors is high (μ close to 1), such that $\eta_d(1 - \mu) - \gamma_b - \mu\gamma_d < 0$, the bank's marginal cost of cyber incidents is increasing with the amount of hidden information by the cloud service provider. Then, increasing the liability of the cloud service provider raises the bank's marginal cost, because the cloud service provider hides more information when its liability is extended.
- **Low impact of disclosure on additional damage:**
  Suppose that the additional damage is not sensitive to the amount of information hidden by the cloud service provider ($\alpha'(v) = 0$). If the transfers received from the cloud service provider are low (i.e., γ_d and γ_b close to zero), the bank's marginal cost of cyber incident is decreasing with the amount of hidden information by the cloud

service provider because $\eta_d(1-\mu) \geq 0$. In that case, higher transfers from the cloud service provider unambiguously decrease the bank's marginal cost.

- **Low impact of disclosure on the ability to claim compensation:**
  If the bank and the depositors' ability to claim compensation is not sensitive to the disclosure of information on cyber incidents ($q'(v) = 0$), the bank's marginal cost of cyber incidents is increasing with the amount of hidden information, and therefore, increasing with the transfers from the cloud service provider.

5.3 Stage 3: the compatibility and the access fees:

At stage 3, the cloud service provider chooses the access fee f^a for its storage service and the compatibility fee f^c. In the rest of the analysis of stage 3, we assume, without loss of generality, that bank A has a higher level of security than bank B following stages 1 and 2, that is, we have $s_A \geq s_B$.

The optimal fees according to the number of outsourcing banks:

Banks' willingness-to-pay for cloud services depend on their respective levels of investment in security, and their incentives to deviate to an asymmetric equilibrium in which they offer different levels of security to their depositors.

If the cloud service provider obtains a positive demand for its storage services, it trades off between setting fees such that both banks join the cloud and become compatible or such that only one bank joins the cloud. If neither of the two banks joins the cloud, the cloud service provider makes zero profit.

Suppose that the cloud service provider serves both bank. As an upstream monopolist, it chooses the profit-maximizing compatibility fee f^{c*} so as to extract banks' additional profit of compatibility. Therefore, the banks will obtain the same profit of using only the storage service (without compatibility), and becoming compatible. In Appendix 2, we show that the equalization of banks' profits in both cases gives

$$f^{c*} \equiv \frac{\beta}{2}(1 - \frac{((\Delta h^c)\rho(v^*)/3)^2}{t(t-\beta)}). \tag{3.17}$$

In addition, the cloud service provider sets the maximum access fee such that each bank does not have the incentives to deviate and becoming independent. Since banks' levels of security may differ after stage 2, one bank may have higher incentives to deviate than the other, and therefore, a lower willingness-to-pay for cloud services. If it serves both banks, the cloud service provider chooses the access fee such that the bank having the lowest willingness-to-pay for the storage service joins the cloud. For this bank, the access fee equalizes the expected marginal cost of cyber incidents if it outsources and if it remains independent. Banks' expected marginal cost of cyber incidents when they join the cloud is $h_i^c \rho(v^*)$, whereas the independent bank has an expected marginal cost given by $h_i^n \rho(0)$. Therefore, in order to join the cloud, the bank that has the lowest willingness-to-pay for cloud services should pay an access fee such that

$$h_i^n \rho(0) = f^a + h_i^c \rho(v^*). \tag{3.18}$$

Consequently, we define for each bank $i \in \{A, B\}$ the maximum access fee such that it has no incentives to deviate and become independent by

$$f_i^{a*} \equiv h_i^n \rho(0) - h_i^c \rho(v^*). \tag{3.19}$$

If $f_A^{a*} \geq f_B^{a*}$ or else if $\theta\rho(v^*) \leq \rho(0)$, the riskiest bank B has the highest willingness-to-pay for cloud services, because its marginal cost (including the limit access fee) $f_B^{a*} + h_i^c \rho(v^*)$ is lower than that of bank A. The reverse is true otherwise. This comparison is important for the results that we obtain in the rest of the analysis.

Suppose now that the cloud service provider serves only one bank. It chooses the access fee that equalizes the bank's marginal cost of joining the cloud and remaining independent. We show in Appendix 2 that if cloud outsourcing increases both banks' marginal costs, the cloud service provider never makes positive profits if only bank A outsources its payment services. This situation happens if the riskiest bank B has the lowest willingness-to-pay for cloud services. The intuition is that the cloud service provider is not able to extract enough rents from bank A, which enjoys high benefits of security differentiation if it remains independent. Therefore, in that case, the cloud service provider serves either both banks, or does not enter the market. The cloud service provider is also ready to subsidize access to extract rents from the compatibility service. Otherwise, if the riskiest bank B has the highest willingness-to-pay for cloud services, the cloud service provider may serve either one or two banks, or decide not to enter the market.

We determine in Lemma 1 the profit-maximizing fees chosen by the cloud service provider according to the number of outsourcing banks.

Lemma 1. If both banks outsource their payment services, the cloud service provider sets a compatibility fee equal to f^{c*}, and it sets an access fee equal to the lowest willingness-to-pay for cloud services, that is

$$min\{f_A^{a*}, f_B^{a*}\} = \begin{cases} f_A^{a*} & \text{if } \theta\rho(v^*) \leq \rho(0) \\ f_B^{a*} & \text{otherwise.} \end{cases}$$

If only the riskiest bank B outsources its payment services, the cloud service provider sets an access fee equal to f_B^{a*}.

Proof. Appendix 2. □

It is interesting to note that the cloud service provider subsidizes access when both banks' marginal cost of cyber incidents increases if they join the cloud, which happens if and only if the riskiest bank has the lowest willingness-to-pay for cloud services.

The cloud service provider's optimal strategy:

We determine the conditions such that the cloud service provider prefers to serve both banks, only the riskiest bank, or remain inactive. At this stage of the game, banks are differentiated in security. However, to simplify the analysis, we focus on the case in which banks take symmetric investment decisions at stage 2, which will happen at the equilibrium of the game. We derive in Proposition 3 the conditions such that the cloud service provider enters the market and serves both banks.[33]

Proposition 13. If banks choose symmetric investments in security, banks outsource their payment services and become compatible if and only if the cloud service provider makes a positive profit, that is, if and only if:

$$\pi_C^c = \beta + f^{a*} - h^c(s_c, s_b^c)L_c(v^*) - C_c(s_c) \geq 0. \tag{3.20}$$

Otherwise, the cloud service provider does not enter the market and banks remain independent.

Proof. Appendix 2. □

Banks join the common private infrastructure managed by the cloud service provider and become interoperable if and only if the magnitude of network effects is sufficiently high. For the cloud service provider, the private benefit of entering the market and serving both banks is equal to the sum of the value of network effects and the access fee (that is, $\beta + f^{a*}$). The private cost is equal to its expected cost of damage and its cost of security investment (or else, $h^c(s_c, s_b^c)L_c(v^*)+C_c(s_c)$). The cloud service provider enters the market when its private benefit exceeds its private cost.

We will show in the next section that an asymmetric equilibrium does not exist in our setting. However, the possibility that banks take asymmetric outsourcing decisions to enjoy the benefits of security differentiation impacts the characterization of the symmetric equilibrium where both banks join the cloud. Indeed, the cloud service provider internalizes banks' incentives to deviate to an asymmetric outsourcing market structure when it chooses the access fee.

[33] All the details with asymmetric investment decisions are given in Appendix 2.

The impact of cloud outsourcing on bank profits and depositor surplus:

In Proposition 4, we detail the effect of cloud outsourcing on the profits of banks and depositor surplus, respectively.

Proposition 14. Suppose that banks have invested symmetric levels of security at stage 2. Cloud outsourcing increases banks' profits if and only if it reduces their security investments (i.e., if $s_b^c \leq s_b^n$). Depositor surplus is higher with cloud outsourcing if and only if

$$\sigma\rho(0)(s_b^c - s_b^n) \geq \frac{\beta}{2}.$$

Proof. See Appendix 3. □

Banks' profits on the deposit market are independent from cyber risk if they choose symmetric levels of investment in security. Therefore, banks benefit from joining the cloud if this decision reduces their expected marginal cost of cyber incidents.

If payment system security is lower in the cloud, depositor surplus is always reduced by cloud outsourcing. The reason is that interoperability softens competition for deposits. Therefore, depositors pay higher prices when payment systems are interoperable in the cloud than when they are fragmented. If payment system security is higher in the cloud, depositor surplus may increase with cloud outsourcing for low values of network effects. In that case, the positive effect of cloud outsourcing on payment system security compensates for the rise in deposit prices.

5.4 Stage 2: banks' investment in security:

For $i \in \{A, B\}$, we denote by $\tilde{p}_i^*$ banks' prices, and by $\tilde{\pi}_i^*(s_i, s_{-i})$ banks' profits, at the equilibrium of stage 3, respectively. At stage 2, each bank $i \in \{A, B\}$ chooses the level of security that maximizes its profit. We focus on banks' best responses when they take symmetric outsourcing decisions and show in the Appendix that the only Nash equilibrium of the subgame in which banks chose their security investments is symmetric (see Appendix 3).[34]

From the envelop theorem, solving for the first-order condition of each bank's profit maximization gives

$$\frac{\partial \tilde{\pi}_i^*}{\partial s_i} = \frac{\partial \pi_i}{\partial s_i} + \frac{\partial \pi_i}{\partial p_{-i}}\frac{\partial \tilde{p}_{-i}^*}{\partial s_i} + \frac{\partial \pi_i}{\partial f_a}\frac{\partial f^{a*}}{\partial s_i} + \frac{\partial \pi_i}{\partial f_c}\frac{\partial f^{c*}}{\partial s_i} = 0. \quad (3.21)$$

[34]We have shown in Proposition 4 that the safest bank never joins the cloud if its competitor does not join it as well. In addition, banks' best responses are identical if they both join the cloud and if only the riskiest bank joins it, because they make the same profits in both cases.

In the equation above, if both banks do not join the cloud, the fees chosen by the cloud service provider have no impact on the bank's profit.

Replacing for each term in Eq.(3.21), we find that

$$\frac{d\tilde{\pi}_i^*}{ds_i} = \sigma\theta((1 - \frac{\Delta h}{3(t-(1-z)\beta)})\frac{\rho(zv^*)}{3} + z\frac{\beta\Delta h^c}{t(t-\beta)}) - k_b s_i, \tag{3.22}$$

where $z = 1$ and $\Delta h = \Delta h^c$ if bank i joins the cloud, and $z = 0$, $\theta = 1$, $\Delta h = \Delta h^n$, otherwise. If both banks remain independent, they invest an amount of security given by

$$s_b^{n*} = \sigma\frac{\rho(0)}{3k_b}, \tag{3.23}$$

and if both banks join the cloud, they invest an amount of security given by

$$s_b^{c*} = \sigma\theta\frac{\rho(v^*)}{3k_b}. \tag{3.24}$$

Depending on their outsourcing decision, bank's marginal cost of security investment is either $k_b s_b^c$ or $k_b s_b^n$. The marginal benefit of security investment is equal to $\sigma\theta\rho(v^*)/3$ when banks join the cloud, because banks only contribute to a share θ of payment system security. When banks do not join the cloud, their marginal benefit is $\sigma\rho(0)/3$. Therefore, banks' investments in cyber security decrease when they join the cloud (compared to the no outsourcing case) if their marginal benefit of security investment increases. Compared to the social optimum, banks reduce their investments in security to soften competition for depositors.

The transfers received from the cloud service provider impact banks' marginal cost $\rho(v^*)$, and therefore, their investment incentives when they join the cloud. The maximum contribution of banks to payment system security is obtained when their marginal cost of cyber incident is maximal. If the cloud service provider is not liable, and if there is a positive proportion of naive consumers (such that $1-\mu > 0$), this is achieved by increasing banks' liability towards their depositors. Determining the transfers from the cloud service provider that maximize banks' marginal cost of cyber incidents is more complex, because of moral hazard. If the amount of hidden information is exogenous, the transfers should be set to zero to maximize banks' investment incentives. However, with moral hazard, positive transfers may improve banks' investment in security. Indeed, banks may decide to invest more to protect themselves from the additional damage that is caused by the under-reporting of cyber incidents. On the other hand, banks may face lower marginal costs when the cloud service provider hides cyber incidents. We detail this effect and its consequences on the cloud service provider's investments in section 5.5.1.

5.5 Stage 1: The equilibrium of the game:

The cloud service provider's investment in security:

At stage 1, the cloud service provider chooses the level of investment in security s_c^* that maximizes its profit π_C^c given in Proposition 4. Solving for the first-order condition gives

$$s_c^* \equiv \sigma(1-\theta)\frac{\overline{\rho}(v^*)}{k_c}, \tag{3.25}$$

where the total marginal cost of cyber incidents internalized by the cloud service provider is given by:

$$\overline{\rho}(v^*) = \rho(v^*) + L_c(v^*), \tag{3.26}$$

where $L_c(v^*) = q(v^*)(\gamma_d + \gamma_b) + K(v^*)$ is given in Eq.(3.1), and $\rho(v^*)$ is given in Eq.(3.15). The cloud service provider's investment in security is maximal when the total marginal cost internalized by the cloud service provider is maximal.

The liability regime for cyber incidents impacts the cloud service provider's investment incentives through two main channels: depositor sophistication and moral hazard.

Suppose first that the amount of hidden information is exogenous. Then, the transfer from the cloud service provider to the banks (γ_b) has no impact on its marginal cost of cyber incident, because it can be extracted through the access fee. The cloud service provider's investment is maximal if the transfer to depositors (γ_d) is maximal, if there is at least a small proportion of naive depositors. In this case, banks do not internalize perfectly the cloud service provider's transfer to the depositors. This implies that their marginal cost does not reflect perfectly the compensation received by the depositors from the cloud service provider. Therefore, the transfer from the cloud service provider to the depositors is not neutral and increases the cloud service provider's marginal cost.

With moral hazard, the impact of the liability regime changes. A higher transfer to the banks (γ_b) is likely to increase the cloud service provider's investment incentives, because the cloud service provider internalizes the additional damage incurred by banks when there is hidden information. If all depositors are sophisticated (i.e, $\mu = 1$), increasing the cloud service provider's transfers to the banks and the depositors, respectively, is the best way to increase its investment incentives. The cloud service provider hides more information, but all firms (including the cloud service provider) invest more to protect themselves from the additional potential damage. However, if there is a positive proportion of naive depositors, the case for increasing the cloud service provider's transfers is less clear. Moral hazard may decrease banks' marginal costs, in which case the cloud service provider benefits from the internalization of banks' cost savings when a cyber incident is hidden.

We conclude this analysis by comparing in Proposition 5 the cloud service provider's investment in security when it is liable and without liability.

Proposition 15. If the minimum amount of hidden information is $\underline{v_c} = 0$, the cloud service provider has higher investment incentives when it is liable than without liability if and only if:

$$(1-\mu)(1-q(v^*))\eta_d \leq (\alpha(v^*)-1)(l_b+\mu l_d)+(1-\mu)q(v^*)\gamma_d+K(v^*). \tag{3.27}$$

Proof. The cloud service provider has higher investment incentives when it is liable than when it is not if and only if its total marginal cost when it is liable (including internalization effects) is higher than its marginal cost with zero liability (with $\gamma_b = \gamma_d = v^* = 0$). □

A liability regime that includes transfers from the cloud service provider may increase the cloud service provider's investment in specific circumstances. The transfers to the bank and to the depositors, respectively, do not have the same effect on the cloud service provider's investment incentives (See Eq.(3.27)). On the one hand, if there is no moral hazard, higher transfers to the depositors increase the cloud service provider's investment incentives if there is a positive proportion of naive depositors. The transfers to the bank are neutral, because the cloud service provider is able to extract them perfectly through the choice of a higher access fee. On the other hand, with moral hazard, there is an additional indirect effect. Higher transfers (either to the banks or to the depositors) affect the cloud service provider's incentives to disclose information when a cyber incident occurs, with ambiguous consequences on the banks' marginal cost (which is extracted through the access fee), as discussed in section 5.2.2. Therefore, because of the internalization effects in a vertical market structure, the transfers to the bank and to the depositors are not equivalent instruments to increase the cloud service provider's investment incentives. Allowing the cloud service provider to compensate the depositors directly is more efficient to improve the security of payment systems than imposing transfers to the banks if there is no moral hazard. With moral hazard, extending the cloud service provider's liability (either towards the banks or the depositors) may sometimes decrease the cloud service provider's investment in security, because banks avoid being liable towards their depositors when the cloud service provider hides a cyber incident. This explains why public authorities resort more often to security standards to ensure a minimum level of security in payment systems.[35]

In practice, financial regulators often expect that their supervised institutions should retain full responsibility for outsourced services. Other regulators (like the Australian APRA) have a more balanced position, which emphasizes the role of the shared responsibility model. In such a framework, each party is accountable for different aspects of security investment and monitoring.

[35]See Appendix 6 for the full details of the impact of the liability regime on security investments.

The equilibrium decisions to join the cloud:

At the equilibrium of the game, from Proposition 3, both banks outsource their payment services if and only if the cloud service provider makes a positive profit. Therefore, the cloud service provider makes a positive profit if and only if the magnitude of network effects is sufficiently high, that is, if and only if $\beta > \max\{0, \widehat{\beta}\}$, with

$$\widehat{\beta} \equiv h^c(s_c^*, s_b^{c*})\overline{\rho}(v^*) - h^n(s_b^{c*})\rho(0) + C_c(s_c^*). \tag{3.28}$$

If $\widehat{\beta} \leq 0$, both banks always join the cloud. This happens if the expected damage incurred by the firms decreases more than the security costs of the cloud service provider, or else, if and only if $k_c < \widehat{k}_c$, where $\widehat{k}_c$ is given in Appendix 4.

5.6 Comparison with the first-best outsourcing policy:

In this section, we analyze why banks make inefficient outsourcing decisions, compared to the first-best.

A benchmark without cyber risk:

If banks' investments in security are exogenous and do not vary with cloud outsourcing, if there is no cyber risk ($h^n = h^c = 0$), cloud outsourcing is socially desirable if and only if $\beta/2 \geq C_c(s_c)$.[36] However, banks take the private decision to outsource their payment system the cloud if and only if $\beta \geq C_c(s_c)$.[37] Therefore, banks decide to join the cloud for an inefficiently low level of network effects. Indeed, the marginal social benefit of outsourcing equals $\beta/2$, as depositors benefit from the possibility to make transactions with the depositors of the other bank. However, banks value excessively the benefits of compatibility with respect to the social optimum. Indeed, *each bank* values its benefit from the compatibility service at $\beta/2$, without internalizing the benefits of compatibility of its competitor. The cloud service provider is able to extract the rents that both banks obtain from compatibility (i.e, $2 * \beta/2$). Therefore, the private benefits of outsourcing are twice as high as the marginal social benefit of outsourcing. This implies that cloud outsourcing occurs for an inefficiently low level of network effects, compared to the social optimum. This result is standard in the literature on network effects (e.g., in Foros and Hansen, 2001).

The distortions caused by cyber risk:

In Proposition 6, we compare banks' outsourcing decisions with cyber risk to the first-best.

[36]This results stems from Proposition 2, with $\Delta L_w = 0$ and $\Delta C_w = C_c(s_c)$.

[37]This results stems from Proposition 3 without cyber risk, and thus, no expected damage and no access fee.

Proposition 16. With cyber risk and different investment levels with and without cloud outsourcing, there may be either excessive outsourcing or under-outsourcing to the cloud compared to the first-best. If $\beta^w > \widehat{\beta}$, banks outsource excessively their payment services when $\beta \in (\widehat{\beta}, \beta^w)$. If $\beta^w < \widehat{\beta}$, banks under-outsource their payment services when $\beta \in (\beta^w, \widehat{\beta})$.

Proof. The difference between banks' private incentives to outsource their payment services and the social optimum depends on $\beta^w - \widehat{\beta}$. We show in Appendix 4 that we may either have $\beta^w - \widehat{\beta} > 0$ or the reverse. □

The presence of cyber risk and the variations of investment costs may offset banks' incentives to take excessive outsourcing decisions, and may even sometimes imply that banks do not outsource enough their payment services. Therefore, our results show that banks' private incentives to outsource their payment services may yield to an inefficient outcome for intermediary values of network effects. However, depending on the market conditions, the inefficiency is either caused by excessive outsourcing, or under-outsourcing. To understand better the mechanisms that drive our result, we explain gradually the distortions that appear when the market is unregulated by adding successively each assumption of our model.

The inefficiencies without cyber risk and exogenous investments:

Suppose that banks' investments in security are exogenous and differ with and without cloud outsourcing. We start by considering that there is neither cyber risk, nor moral hazard. For exogenous levels of investment, the regulator prefers that both banks join the cloud if and only if $\beta/2 \geq \Delta C_w$, with $\Delta C_w = 2(C_b((s_w^c)^b) - C_b(s_w^n)) + C_c(s_c)$. If banks' costs of security increase with cloud outsourcing when the market regulated (i.e, $C_b((s_w^c)^b) - C_b(s_w^n)) > 0$), this reinforces the bias towards excessive outsourcing compared to the first-best. Indeed, the cloud service provider does not internalize banks' investment costs when it assesses the benefits of offering its services to both banks. By contrast, if banks' investment are lower with cloud outsourcing when the market is regulated, this may reduce the difference between the private choices to outsource the payment services and the social optimum (i.e, $\beta^w - \widehat{\beta}$).

The inefficiencies with cyber risk, exogenous investments but without moral hazard:

The presence of cyber risk adds another layer of inefficiency compared to the first-best. Suppose that there is no moral hazard, and that the minimal social damage is identical with and without cloud outsourcing ($\underline{\alpha} = 1$). Continuing the analysis with exogenous levels of risk h^c and h^n, from Proposition 2, we see that cloud outsourcing is socially desirable if and only if $\beta/2 \geq \Delta L_w + \Delta C_w$. The marginal social cost of outsourcing now includes the variation of the total loss incurred by the banks, the cloud service provider and the depositors, given by:

$$\Delta L_w = (h^c - h^n)l.$$

With private outsourcing decisions, the cloud service provider internalizes imperfectly the variation of the total loss caused by outsourcing. The cloud service provider's marginal cost of outsourcing is the sum of its own expected loss and the variation of the banks' expected loss, which are internalized through the choice of the access fee, and it is given by

$$h^c \overline{\rho}(0) - h^n \rho(0),$$

with $\rho(0) = l - (1-\mu)(l_d - \eta_d)$ and $\overline{\rho}(0) = \rho(0) + (1-\mu)\gamma_d$. The marginal additional loss internalized by the cloud service provider is lower that the variation of the social loss caused by outsourcing if and only if

$$(1-\mu)((h^c - h^n)(l_d - \eta_d) - h^c \gamma_d) > 0.$$

If the private investment levels are exactly identical to the welfare-maximizing levels of investment, there is a distortion if some depositors are naive ($\mu < 1$). Banks internalize a lower share of the variation of the depositors' losses caused by the decision to outsource than in the first-best scenario. If cyber risk increases with the outsourcing (i.e., $h^c > h^n$), banks incur a marginal cost of outsourcing which is too low with respect to the marginal social cost, and they incur a marginal cost of outsourcing which is too high otherwise. This effect implies that there is either under-outsourcing or over-outsourcing. In addition, the transfer of the cloud service provider to the depositors is not neutral when some depositors are naive. The cloud service provider's total marginal cost increases when it has to give a higher amount of compensation to the depositors. The transfer mechanism is useful to limit the over-outsourcing problem when cyber risk increases but it amplifies the under-outsourcing problem otherwise.

The inefficiencies with cyber risk, exogenous investments and moral hazard:

The presence of moral hazard impacts the variation of the total loss caused by outsourcing with exogenous levels of investment. We have seen that moral hazard impacts the total damage internalized by the bank, and therefore, by the cloud service provider (see Eqs.(15) and (25)). If the cloud service provider internalizes a higher share of the damage because of moral hazard, this reduces the bias towards excessive outsourcing (see Eq.(28)). This is the case for instance if the depositors' ability to claim compensation is not sensitive to the disclosure of information on cyber incidents. However, if the cloud service provider internalizes a lower share of the damage, the bias towards excessive outsourcing is reinforced. This happens if the additional damage is not sensitive to moral hazard, if the cloud is not liable, and if the ability to claim compensation is very sensitive to moral hazard.

The inefficiencies with endogenous investments:

Finally, the magnitude of all effects depends on security investments if they are endogenous. First, moral hazard changes banks' investments incentives. If banks' invest more to protect themselves from the additional damage caused by moral hazard, the cloud service provider has a higher marginal cost of outsourcing, because it extracts lower rents. Therefore, this effect reduces the bias towards excessive outsourcing compared to the first-best. Second, banks do not take into account the effect of their investments on the damage incurred by the cloud service provider when they choose how much to invest in security, which reduces their investment incentives compared to the first-best. Also, both banks and the cloud service provider choose their levels of investment without internalizing the effect of the outsourcing on the expected damage of myopic depositors if they are not liable for the damage. The under-investment of the cloud service provider always leads to over-outsourcing, because the cloud service provider has higher incentives to enter the market when its profit increases. However, the under-investment of banks may increase or decrease the incentives of the cloud service provider to enter the market with respect to the first-best, depending on their effect on the rents that the cloud service provider extracts through the access fee.

The liability regime and banks' outsourcing decisions:

The liability regime for cyber incidents may not suppress the distortion caused by the presence of naive depositors. However, it may impact the distortions caused by moral hazard and affect the players' investment incentives. One interesting question is whether increasing the cloud service provider's liability may provide banks with higher incentives to become interoperable. The answer to this question is not clear. On the one hand, raising the cloud service provider's marginal cost may reduce the cloud service provider's expected loss, which may lower the threshold value of network externalities such that banks become interoperable. On the other hand, the cloud service provider has incentives to increase its investment in security, which may increase its investment cost. This effect may reduce the cloud service provider's incentives to enter the market. Therefore, a liability regime with transfers from the cloud service providers to the banks and the depositors may not necessarily provide banks with higher incentives to become interoperable. This might not be a concern if banks tend to outsource excessively to the cloud in a given market, but could be more problematic if banks do not rely on a joint payment infrastructure when this would be socially desirable.

Alternative regulations:

In this section, we discuss the potential remedies to the inefficiencies that arise when banks make private outsourcing decisions.

i) Regulatory control of cloud outsourcing agreements:

The financial regulator can intervene in the market by refusing to authorize cloud outsourcing when there is excessive outsourcing. This could happen in several countries (e.g., England, Australia), where banks need to show their outsourcing agreements to the financial supervisor before joining the cloud. Therefore, it is possible to use the supervision of outsourcing agreements to correct the bias towards excessive outsourcing. However, this regulatory tool is inefficient to correct for the bias towards under-outsourcing that is caused by the presence of cyber risk. In addition, one potential difficulty with this type of regulatory tool consists in establishing precise criteria for authorizing cloud outsourcing agreements.

So far, in the welfare analysis, we have studied the case in which the regulator controls firms' decisions to outsource their payment services and their levels of security investments. Another possibility is that the regulator only controls outsourcing decisions at stage 3 after the cloud has chosen its prices and firms have invested in security (see Appendix 7). Since there is an imperfect disclosure of cyber incidents with cloud outsourcing, the regulator authorizes banks to outsource their payment service for a higher degree of network externalities than in the first-best.

The effect of banks' investment in security on the regulator's incentives to authorize outsourcing is twofold. First, with and without cloud outsourcing, banks reduce their investment in security to soften competition for deposits compared to the first-best. If this effect has more consequences on social welfare when banks outsource (i.e., if $\theta\alpha(v^*) > 1$), the regulator prefers that banks remain independent. Otherwise, it prefers that both banks outsource. Second, the compensation offered by the cloud service provider and moral hazard imply that banks internalize less damage when they outsource, which increases the regulator's incentives not to authorize outsourcing, compared to the first-best.

Unlike banks, the cloud service provider may either over-invest or under-invest in security with respect to the first-best. If its reputation cost is high enough (i.e., if $K(v^*) > \alpha(v^*)(1-\mu)L_d(v^*)$), the cloud service provider may increase its security investment, which offsets partially the fact that banks internalize less damage. However, this is not sufficient to increase the overall level of security. It follows that the regulator has lower incentives to authorize outsourcing than in the first-best.[38]

To conclude, if banks keep a high share of investment in payment system security (i.e., if θ is high enough) or if the cloud service provider is likely to under-report cyber incidents, the inability of the supervisor to implement first-best security decisions restricts its incentives to promote outsourcing. However, if banks delegate a high share of their

[38]If the cloud service provider over-invests in security, this does not compensate for the fact that banks under-invest when they join the cloud, because the probability of attack is linear in each player's investment.

investment in security to the cloud service provider, and if the latter is disciplined by a private reputation cost in case of a cyber incident, the regulator may prefer to delegate the management of the payment system infrastructure to the third-party provider rather than to the banks.

ii) The shared responsibility model:

Another option for the financial regulator consists in by assessing ex ante the perimeter of responsibility of the cloud service provider and the banks, in terms of investment and maintenance of the security of the joint payment system. The Australian regulator (APRA) calls this regulatory option "the shared responsibility model".

In that case, we assume that a cyber incident occurs in a bank with probability $h^b = \theta(h - \sigma s_b)$, and in the cloud with probability $h^c = (1-\theta)(h - \sigma s_c)$, respectively. Compared to our setting, the probability that the system is attacked and firms' contribution to security investment remain unchanged. The only difference with respect to our benchmark setting is that a firm only compensates the other parties (the depositors for the banks, and the depositors and the banks for the cloud) when the cyber incident occurs in its perimeter of responsibility.

We denote by s_b^{sr*} and s_c^{sr*} the respective security investment of the outsourcing banks and of the cloud service provider under the shared responsibility model. Replacing for $\rho(v^*)$ in the equilibrium security investments s_b^{c*} and s_c^* given in Eq.(3.24) and Eq.(3.25) gives the banks' security investment:

$$s_b^{sr*} = s_b^{c*} + \sigma\theta \frac{\gamma_b + \mu\gamma_d}{3k_b},$$

and the cloud service provider's investment:

$$s_c^{sr*} = s_c^* - \sigma(1-\theta)\frac{(1-\mu)\eta_d}{k_c}.$$

With the shared responsibility model, if a cyber incident hits a bank, its internalized damage increases by $\gamma_b + \mu\gamma_d$, compared to our benchmark setting. The cloud service provider no longer compensates the banks nor their depositors in that case, which increase banks' liability. This makes the depositors more sensitive to banks' security investments. Therefore, the access fee decreases, and banks invest more in security than in our benchmark setting. If a cyber incident hits the cloud service provider, the damage internalized by the bank decreases by $(1-\mu)\eta_d$, because the bank does not compensate its depositors. Since banks' expected marginal cost of cyber incidents decreases, they pay a higher access fee. Therefore, the sensitivity of depositor demand to the investment of the cloud service provider decreases.

The shared responsibility model has two effects on banks' investment incentives compared to our setting. On the one hand, since the sensitivity of sophisticated depositors to banks' investments increases if the cyber incident occurs in the bank, banks invest more in security. On the other hand, when the cyber incident occurs in the cloud, banks do not compensate their depositors. Therefore, their marginal cost decreases, because they do not take into account the damage of myopic depositors. This reduces their investment incentives compared to our setting. The first effect dominates the second effect if the proportion of myopic depositors is sufficiently low. Therefore, banks invest more in security than in our setting with the shared responsibility model if the proportion of sophisticated depositors is sufficiently high.

iii) Mandatory levels of investment in security:

Another option for the regulator consists in setting up security standards that are equal to the first-best levels of security investments for each player. If firms always comply with the standard, this affects banks' incentives to join the cloud.[39] However, this second-best policy instrument may not correct for the distortions that arise in the vertical structure, and in particular, the fact that the cloud service provider internalizes imperfectly the damage.

iv) Public management of a common infrastructure in the cloud:

We examine one last policy option, which consists in deciding to build a public cloud when this is socially desirable. In that case, the regulator is able to decide how much to invest in cloud security for the shared infrastructure, and the banks may choose ex post their levels of investment for their part of the system, before competing in the market for deposits. This option has been chosen by several emerging countries for the development of a joint payment infrastructure (see Pix in Brazil or UPAI in India).

Suppose that the regulator wishes to foster interoperability because this option is socially efficient. Then, it chooses the access and the compatibility fee that maximize social welfare, and the maximum level of disclosure for cyber incidents. Since the access fee and the compatibility fee are neutral, the fees chosen by the regulator remain indeterminate, under the constraints that banks do not deviate from the equilibrium in which they both join the cloud and become compatible.

If the regulator faces the same constraints as the cloud service provider in our setting, the possibility to choose the service fees does not change social welfare with respect to the situation of (iii) with mandatory investments (see Appendix 7). Indeed, the regulator needs to choose its fees such that banks join the common infrastructure when it is socially optimal. As in our benchmark setting, fees have no effect on banks' security decision

[39] This may not be the case that firms comply with the standard. In that case, the regulator may incur the costs of auditing firms regularly.

when they both outsource. Also, if only one bank outsources, the regulator's objective remains constrained by banks' incentives, and it either sets a maximum or a minimum access fee such that only one bank outsources. Anticipating this fee pricing, banks choose symmetric levels of investment in security, and the regulation of fees does not increase banks' investment in security.

In some cases, the regulator could be able to choose the prices of the cloud services at the same time as banks' investments in security. The regulator can set a maximum compatibility fee such that one bank (say, bank A) is indifferent between using the compatibility service and using only the storage service, given that it may choose different security investments in each situation. This subgame, where the regulator maximizes its fee setting with respect to the incentive of one bank A, and both banks choose their security decision, admits a Nash Equilibrium, but it implies both positive and negative effects on social welfare (see Appendix 8). On the one hand, this reinforces the incentives of the rival bank B to invest in security. Indeed, this compatibility fee setting suppresses the incentives of bank A to react to investment changes of its competitor, such that the indirect effect disappear in the investment decision of bank B. In Appendix 7, we show that the optimal security investment of bank B doubles with respect to the situation where the regulator sets its compatibility fee after banks have invested. On the other hand, bank A has indeterminate incentives to invest, because the fee exactly compensates for its benefit from compatibility, including its effect on its investment decision. Thus, this compatibility may either correct the under-investment problem of bank A, or it may reinforce it. As a consequence, the regulator faces a trade-off between setting a high compatibility fee, which maximizes the incentives of one bank to invest, and setting a low compatibility fee, which preserves all banks' incentives to invest.

6 Conclusion:

In this paper, we have discussed the impact of the liability regime for cyber incidents on banks' decisions to outsource their payment system, and on the expected level of security. We have shown that imposing transfers from the cloud service provider to the banks and the depositors may improve its investment incentives and interoperability, when specific market conditions are met. The presence of moral hazard may change the impact of the liability regime on the cloud service provider's investment incentives. This explains why public authorities have chosen recently to focus on the possibility to audit cloud service providers to reduce the role of moral hazard. While moral hazard cannot be completely eliminated, limiting its effect on the players' investment incentives may clarify the role of the liability regime for cyber incidents in banking retail markets. Currently, in most countries, banks may not outsource their responsibilities. However, other policy options may be considered in the future. In this respect, the point of view of the Australian financial regulator (APRA) which is encouraging shared responsibility models before authorizing cloud outsourcing by banks is interesting.

Bibliography

[1] Amir, E., Levi, S. & Livne, T. (2018): "Do firms underreport information on cyber-attacks? Evidence from capital markets," *Review of Accounting Studies*, 23(3), 1177–1206. doi:10.1007/s11142-018-9452-4

[2] Anderson, R. and Moore, T. (2009): "Information security: where computer science, economics and psychology meet," *Philosophical Transactions of the Royal Society A*. 367(1898), 2717–2727. doi:10.1098/rsta.2009.0027

[3] Bank for International Settlements (2022): "Annual Economic Report," June.

[4] Bank of Canada (2019): "Financial System Review," 19–22.

[5] Bianchi, M., Bouvard, M., Gomes, R., Rhodes, A. & Shreeti, V. (2022): "Mobile Payments and Interoperability: Insights from the Academic Literature," *HAL Working Papers*.

[6] Bourreau, M., Cambini, C. & Hoernig, S. (2018): "Cooperative investment, access, and uncertainty," *International Journal of Industrial Organization*, 56, 78–106. doi:10.1016/j.ijindorg.2017.11.004

[7] Chande, N. & Yanchus, D. (2019): "The cyber incident landscape," *Bank of Canada Staff Analytical Note*, 2019(32).

[8] Chiu, J. & Wong, T.N. (2022): "Payments on digital platforms: Resiliency, interoperability and welfare," *Journal of Economic Dynamics and Control*, 142, 104173. doi:10.1016/j.jedc.2021.104173

[9] Covert, E. (2021): "Case Study: AWS and Capital One.," *System Weakness*.

[10] Creti, A. & Verdier, M. (2014): "Fraud, investments and liability regimes in payment platforms," *International Journal of Industrial Organization*, 35, 84–93. doi:10.1016/j.ijindorg.2014.06.003

[11] Daughety, A.F. & Reinganum, J.F. (1995): "Product safety: liability, R&D, and signaling," *The American Economic Review*, 1187–1206.

[12] Daughety, A.F. & Reinganum, J.F. (2005): "Secrecy and safety," *American Economic Review*, 95(4), 1074-1091. doi:10.1257/0002828054825673

[13] Daughety, A.F. & Reinganum, J.F. (2013): "Economic analysis of products liability: Theory," *Research handbook on the economics of torts*, 69–96. doi:10.4337/9781781006177.00011

[14] De Cornière, A. & Taylor, G. (2020): "A model of information security and competition," *TSE Working Paper*, 21-1285.

[15] Doğan, P. (2009): "Vertical networks, integration, and connectivity," *Journal of Economics & Management Strategy*, 18(2), 347–392. doi:10.1111/j.1530-9134.2009.00217.x

[16] D'Silva, D., Filková, Z., Packer, F. & Tiwari, S. (2019): "The design of digital financial infrastructure: lessons from India," *BIS Paper*, 10.

[17] European Banking Authority (2019): "EBA guidelines on ICT and security risk management," *Internal Governance Final Report*, 04.

[18] Federal Reserve System, Federal Deposit Insurance Corporation, & Comptroller of the Currency (2021): "Proposed Interagency Guidance on Third-Party Relationships: Risk Management," *US Federal Register*, 15308.

[19] Foros, Ø. & Hansen, B., (2001): "Competition and compatibility among Internet service providers," *Information Economics and Policy*, 13(4), 411–425.

[20] Financial Stability Board (2019): "Third-party dependencies in cloud services: considerations on financial stability implications," *FSB Publication*, 9.

[21] Garratt, R. & Schilling, L. (2022): "Optimal Data Security with Redundancies," *Working Paper SSRN*, 4138065. doi:10.2139/ssrn.4138065

[22] Grabowski, M. (2021): "Legal Aspects of "White-Label" Banking in the European, Polish and German Law. *Journal of Risk and Financial Management*, 14(6), 280. doi:10.3390/jrfm14060280

[23] Horvath, V., Klaver, M., Roosendaal, A., Cave, J., & Robinson, N. (2014): "Data and security breaches and cyber-security strategies in the EU and its international counterparts," *EU Publications Office*, doi:10.2861/32110

[24] House of Commons Treasury Committee (2019): "IT failures in the financial services sector.," *Second Report of Session*, 2019–20.

[25] International Data Corporation (2018): "Worldwide Public Cloud Services Spending Forecast to Reach $160 Billion This Year, According to IDC," *Business Wire.*

[26] Inderst, R. & Peitz, M. (2012): "Market asymmetries and investments in next generation access networks," *Review of Network Economics*, 11(1). doi:10.1515/1446-9022.1323

[27] Jacob, J. & Lovat, B. (2016): "Multiple tortfeasors in high risk industries: how to share liability?," *BETA Working Paper*, 35.

[28] Kahn, C.M. & Roberds, W. (2008): "Credit and identity theft," *Journal of Monetary Economics*, 55(2), 251–264.

[29] Kahn, C.M., Rivadeneyra, F. & Wong, T.N. (2020): "Eggs in one basket: security and convenience of digital currencies," *FRB St. Louis Working Paper*, 2020-032. doi:10.20955/wp.2020.032

[30] Malueg, D.A. & Schwartz, M. (2006): "Compatibility incentives of a large network facing multiple rivals," *The Journal of Industrial Economics*, 54(4), 527–567. doi:10.1111/j.1467-6451.2006.00299.x

[31] Lam, W.M.W. (2016): "Attack-prevention and damage-control investments in cybersecurity," *Information Economics and Policy*, 37, 42–51. doi:j.infoecopol.2016.10.003

[32] Lam, W.M.W. & Seifert, J. (2021): "Regulatory interactions and the design of optimal cybersecurity policies, *Digital Security by Design reports.*

[33] Matutes, C. & Padilla, A.J. (1994): "Shared ATM networks and banking competition," *European Economic Review*, 38(5), 1113–1138. doi:10.1016/0014-2921(94)90040-X

[34] Reserve Bank of New Zeland (2020): "Risk management guidance on cyber resilience and views on information gathering and sharing," *Consultation Paper.*

[35] Robinson, N., Valeri, L., Cave, J., Starkey, T., Graux, H., Creese, S. & Hopkins, P.P. (2011): "The cloud: understanding the security, privacy and trust challenges," *RAND Corporation.*

[36] Rochet, J.C. (2003): "The theory of interchange fees: a synthesis of recent contributions," *Review of Network Economics*, 2(2). doi:10.2202/1446-9022.1021

[37] Segal, I. (1999): "Contracting with externalities," *The Quarterly Journal of Economics*, 114(2), 337-388. doi:10.1162/003355399556016

[38] Southwell, A.H., Vandevelde, E., Bergsieker, R. & Bisnar Maute, J. (2017): "Gibson Dunn Reviews US Cybersecurity and Data Privacy," *The CLS Blue Sky Blog (Columbia Law School).*

[39] Stadler, M., Trexler, C.T. & Unsorg, M. (2022): "The perpetual trouble with network products: why IT firms choose partial compatibility," *Networks and Spatial Economics*, 1–11.

[40] Valletti, T.M. & Cambini, C. (2005): "Investments and network competition," *RAND Journal of Economics*, 446–467.

[41] Verdier, M., (2011): "Interchange fees in payment card systems: a survey of the literature," *Journal of Economic Surveys*, 25(2), 273–297. doi:10.1111/j.1467-6419.2009.00607.x

Appendix

Appendix 1 - Welfare-maximizing investments in security and outsourcing decisions:

Comparison of welfare-maximizing security investments:
Using the calculations of s_w^c and s_w^n given in Eq.(3.10) and Eq.(3.8), respectively, we have that $s_w^c \geq s_w^n$ if and only if $1 - \theta^2 \underline{\alpha} \leq 0$ or $1 - \theta^2 \underline{\alpha} > 0$ and

$$k_c \leq k_s \equiv 2k_b \frac{(1-\theta)^2 \underline{\alpha}}{1 - \theta^2 \underline{\alpha}},$$

where $k_s \geq 0$. The condition $1 - \theta^2 \underline{\alpha} \leq 0$ is equivalent to $\Delta s_b \leq 0$.

Comparison of social welfare with and without cloud outsourcing:
Replacing for s_w^c given in Eq.(3.10) into W_c given in Eq.(3.9), and for s_w^n given in Eq.(3.8) into W_n given in Eq.(3.7), outsourcing increases social welfare if and only if $W_c > W_n$, which happens if and only if $\beta > \max\{0, \beta_w\}$, with

$$\beta_w = 2h(\underline{\alpha} - 1)l - \sigma^2 \left(\frac{(\underline{\alpha} l(1-\theta))^2}{k_c} + \frac{(\theta \underline{\alpha} l)^2 - l^2}{2k_b} \right). \tag{3.29}$$

Solving for k_c in Eq.(3.29), we find that $\beta_w < 0$ if and only if $k_c < k_w$, where

$$k_w \equiv \frac{2k_b \sigma^2 (1-\theta)^2 \underline{\alpha}^2 l}{4hk_b(\underline{\alpha} - 1) - \sigma^2 l(\underline{\alpha}^2 \theta^2 - 1)},$$

and $4hk_b(\underline{\alpha} - 1) > \sigma^2 l(\underline{\alpha}^2 \theta^2 - 1)$ from Assumptions (A1) and (A2), such that $k_w > 0$. Denoting $C_b^n = (\sigma l)^2/(4k_b)$ and rearranging, we find that

$$k_w = \frac{2k_b(1-\theta)^2 \underline{\alpha}^2 C_b^n}{(1 - \underline{\alpha}^2 \theta^2) C_b^n + (\underline{\alpha} - 1)hl}.$$

Factorizing by $k_s = 2k_b(1-\theta)^2 \underline{\alpha}/(1 - \theta^2 \underline{\alpha})$ and assuming that $\theta^2 \underline{\alpha} \neq 1$, we obtain the expression of k_w given in Proposition 2, that is,

$$k_w = k_s \frac{(1 - \theta^2 \underline{\alpha}) C_b^n}{(1 - \theta^2 \underline{\alpha}^2) C_b^n + (\underline{\alpha} - 1)hl}.$$

Appendix 2

Competition stage when only one bank outsources: As in the main text, we assume, without loss of generality, that bank A is safer than bank B after stage 2, that is, we have $s_A \geq s_B$.

In the following, we consider the competition stage if only one bank outsources. If bank $i \in \{A, B\}$ does not outsource, no depositor benefits from the compatibility service. As a consequence, the outsourcing bank $-i$ does not pay any compatibility fee f^c. At the equilibrium, depositors' expectations are fulfilled, such that the independent bank i faces a total demand N_i^o equal to

$$N_i^o = \frac{1}{2} + \frac{p_{-i}^o - p_i^o - \mu h_i^n L_d(0) + \mu h_{-i}^c L_d(v^*)}{2(t-\beta)},$$

and the cloud bank $-i$ faces a total demand N_{-i}^o equal to

$$N_{-i}^o = \frac{1}{2} + \frac{p_i^o - p_{-i}^o - \mu h_{-i}^c L_d(v^*) + \mu h_i^n L_d(0)}{2(t-\beta)}. \tag{3.30}$$

At the competition stage, the independent bank i chooses p_i^o to maximize

$$\pi_i^o = (p_i^o - h_i^n L_b(0))N_i^o - C_b(s_i) \tag{3.31}$$

while the cloud bank $-i$ chooses p_{-i} to maximize

$$\pi_{-i}^o = (p_{-i}^o - f^a - h_{-i}^c L_b(v^*))N_{-i}^o - C_b(s_{-i})\ . \tag{3.32}$$

Solving for the first-order conditions in Eqs.(3.31) and (3.32), the prices of deposits of banks i and $-i$ are equal to

$$p_i^o = t - \beta + h_i^n L_b(0) + \frac{f^a}{3} - \frac{h_i^n \rho(0) - h_{-i}^c \rho(v^*)}{3}, \tag{3.33}$$

and

$$p_{-i}^o = t - \beta + h_{-i}^c L_b(v^*) - \frac{2f^a}{3} - \frac{h_{-i}^c \rho(v^*) - h_i^n \rho(0)}{3},$$

respectively. The profit of the independent bank i at the competition stage equals

$$\pi_i^o(s_i, s_{-i}, s_c, f^a) = \frac{(t-\beta+(f^a + h_{-i}^c \rho(v^*) - h_i^n \rho(0))/3)^2}{2(t-\beta)} - C_b(s_i), \tag{3.34}$$

and the profit of the cloud bank $-i$ equals

$$\pi_{-i}^o(s_i, s_{-i}, s_c, f^a) = \frac{(t-\beta-(f^a + h_{-i}^c \rho(v^*) - h_i^n \rho(0))/3)^2}{2(t-\beta)} - C_b(s_i). \tag{3.35}$$

Fee setting by the CSP: The cloud service provider sets the fees f^a and f^c to maximize its profit, which equals π_C^c given in Eq.(3.5) if both banks outsource, and π_C^o in Eq.(3.6) if only bank $-i$ outsources. We distinguish these two situations below, before comparing the profit of the cloud service provider in each case.

Case A: Both banks outsource: If both banks A and B store their payment services in the cloud, the cloud service provider always prefers to offer the compatibility service because it can be offered at no additional cost. In that case, the cloud service provider sets the fees f^a and f^c to maximize its profit π_C^c given in Eq.(3.5), under the constraint that no bank deviates from the situation where they both use the compatibility service. Because banks pay the same fee to the cloud service provider, and since the deposit market is always covered, π_C^c is linear in f^c and f^a. Therefore, the maximization problem of the cloud service provider is equivalent to:

$$\max_{f^c, f^a} \quad 2f^c + f^a$$

$$\text{s.t.} \quad \pi_i^c(f^c, f^a) \geq \pi_i^{st} \quad \text{for i=\{A,B\}} \tag{C1a}$$

$$\pi_i^c(f^c, f^a) \geq \pi_i^o(f^a) \quad \text{for i=\{A,B\}} \tag{C2a}$$

$$\pi_C^c \geq 0. \tag{C3a}$$

In the constraints above, π_i^c represents the profit of bank i when both banks use the compatibility service, and it is obtained by setting $v = v^*$ and $z = 1$ in π_i given in Eq.(3.14). The profit π_i^{st} is the profit of bank i when both banks only use the storage service and it is obtained by setting $v = v^*$ and $z = 0$ in π_i given in Eq.(3.14). The profit π_i^o given in Eq.(3.34) is the profit of bank i when it remains independent, while its rival uses the storage service.

The interpretation of this maximization problem is as follows. Given that the compatibility and the storage services are one-way complements, there are two possible deviations from the situation in which both banks use the two services. First, each bank should not deviate by remaining independent, if its rival outsources (constraints C1a). Second, banks should not deviate by not using the compatibility service, if their rival uses it and both banks outsource (constraints C2a). Finally, condition (C3a) states that the cloud service provider makes a positive profit.

Replacing for π_i^c and π_i^s defined above into (C1a) for both banks A and B, we find that the constraints (C1a) are equivalent to $f^c \leq f^{c*}$, where f^{c*} is given in Eq.(3.17). Since the profit of the cloud service provider π_C^c is increasing with f^c, the cloud service provider chooses the compatibility fee f^{c*} when both banks outsource.

Replacing for $f^c = f^{c*}$, π_i^c and π_i^{st} defined above into (C2a), the constraint (C2a) for bank i is equivalent to $(f_i^{a*} - f^a)(f^a + \tau_1) \geq 0$, with $f_i^{a*} = h_i^n\rho(0) - h_i^c\rho(v^*)$ and $\tau_1 \equiv 6(t - \beta) - h_i^c\rho(v^*) + 2h_{-i}^c\rho(v^*) + h_i^n\rho(0)$. From Assumption (A1), we have that $\tau_1 \geq 0$ and $\tau_1 \geq f_i^{a*}$. Therefore, the constraint (C2a) is satisfied for bank i if and only if $f^a \in (-\tau_1, f_i^{a*})$. Since the profit of the cloud service provider is increasing with f^a, the latter chooses the maximum access fee such that the constraint (C2a) is satisfied for both banks A and B. Therefore, it sets an access fee equal to $min\{f_A^{a*}, f_B^{a*}\}$.

Replacing for $h_i^n = h - \sigma s_i$ and $h_i^c = h - \sigma(\theta s_i + (1-\theta)s_c)$ in f_A^{a*} and f_B^{a*}, we find that $f_B^{a*} \geq f_A^{a*}$ is equivalent to

$$\theta\rho(v^*) \geq \rho(0). \tag{3.37}$$

To conclude for Case A, the cloud service provider chooses an access fee equal to f_A^{a*} if $\rho(v^*) \geq \theta\rho(0)$ and $\pi_C^c(\, f^{c*},\, f_A^{a*}) \geq 0$. It chooses an access fee equal to f_B^{a*} if $\rho(v^*) < \theta\rho(0)$ and $\pi_C^c(\, f^{c*},\, f_B^{a*}) \geq 0$, and it prefers not outsource to both banks otherwise.

Case B: Bank $i \in \{A, B\}$ does not outsource: In this case, the cloud service provider does not provide a compatibility service, and it only chooses the access fee f^a to maximize its profit π_C^o in Eq.(3.6), under the constraint that no bank has incentives to deviate from the situation in which only one bank (here, bank $-i$) uses the storage service. The maximization problem of the cloud service provider is equivalent to

$$\begin{aligned} \max_{f^a} \quad & \pi_C^o \\ \text{s.t.} \quad & \pi_{-i}^o(f^a) \geq \pi_{-i}^n && \text{(C1b)} \\ & \pi_i^o(f^a) \geq \pi_i^s && \text{(C2b)} \\ & \pi_C^o \geq 0 && \text{(C3b)} \end{aligned}$$

In the constraints above, π_i^o and π_{-i}^o represent the profit of banks i and $-i$ when only bank $-i$ uses the storage service of the cloud service provider, and they are given in Eqs.(3.34)-(3.35), respectively. The profit π_{-i}^n represents the profit of bank $-i$ when no bank outsources, and it is obtained by setting $v = 0$ and $z = 0$ in π_i given in Eq.(3.14). Finally, the profit π_{-i}^s represents the profit of bank $-i$ when both banks only use the storage service, and it is obtained by setting $v = v^*$ and $z = 0$ in π_i given in Eq.(3.14).

The interpretation of the constraints is as follows. If bank i does not outsource, bank $-i$ can deviate by refusing to outsource as well, such that both banks are independent (constraint C1b). Second, bank i can deviate by using the storage service too (constraints C2b). Third, the cloud service provider must make a positive profit (constraint C3b).

Following the analysis of the constraint (C2a) in Case A above, where $\pi_i^c(f^c) = \pi_i^s$ from the constraint (C1a), the constraint (C2b) is equivalent to $f^a \leq f_{-i}^{a*}$, with $f_{-i}^{a*} = h_{-i}^n\rho(0) - h_{-i}^c\rho(v^*)$. In addition, the constraint (C1b) is equivalent to $f^a \geq f_i^{a*}$.

We now determine the maximum of π_C^o with respect to f^a and show that the constraint (C1a) is binding. Differentiating π_C^o wth respect to f^a, we find that $\partial\pi_C^o/\partial f^a = (f_m^a - f^a)/(3(t-\beta))$, with

$$f_m^a \equiv \frac{3(t-\beta) + h_{-i}^c(L_c(v^*) - \rho(v^*)) + h_i^n\rho(0)}{2}.$$

Since π_C^o is concave in f^a, this profit function reaches a maximum at $f^a = f_m^a$. From Assumption (A1), we have $f_m^a - f_{-i}^{a*} \geq 3(t-\beta)/2 - h_{-i}^n\rho(0) \geq 0$. Therefore, the condition

(C1b) constrains the maximum fee that may be chosen by the cloud service provider. The constraints (C1b) and (C2b) imply that the cloud service provider sets an access fee equal to $f^{a*} = f_{-i}^{a*}$ if $f_{-i}^{a*} \geq f_i^{a*}$ and if constraint (C3b) holds. Otherwise, it does not outsource only to bank $-i$.

We show that a necessary condition for condition (C3b) to hold is that $f^{a*} = f_i^{a*} > 0$. Since f_i^{a*} is decreasing with h_i^c for bank $i \in \{A, B\}$ and h_i^c is decreasing with the investment of the cloud service provider s_c, f_i^{a*} is increasing with s_c. Given that $s_c \leq h/\sigma$, we have $f_i^{a*} \leq f_i^{a*}|_{s_c=h/\sigma}$, with $f_i^{a*}|_{s_c=h/\sigma} = (h - \sigma s_i)(\rho(0) - \theta\rho(v^*))$. If $\rho(0) < \theta\rho(v^*)$, the fee $f_i^{a*}|_{s_c=h/\sigma}$ is negative, which implies that f_i^{a*} is negative. Therefore, if $\rho(0) < \theta\rho(v^*)$, the cloud service provider cannot make a positive profit when it serves only bank $-i$.

To conclude, from Eq.(3.37), if $\rho(0) > \theta\rho(v^*)$ and the constraint (C3b) is satisfied, the cloud service provider sets an access fee equal to f_B^{a*} such that only bank B outsources. Otherwise, it does not provide a storage service to one bank only.

Comparison of CSP profits of serving either one or two banks: We are now able to determine the number of banks that the cloud service provider prefers to serve at the equilibrium of stage 3. Assume that $\rho(0) \geq \theta\rho(v^*)$, such that the cloud service provider faces a non-trivial trade-off between serving both banks or bank B only. In that case, the cloud service provider charges an access fee equal to f_A^{a*} when it serves both banks and f_B^{a*} when it serves only bank B.

Suppose that the cloud service provider serves only bank B. We start by determining the demand of bank B at the profit-maximizing fees chosen by the cloud service provider, before determining the cloud service provider's profit. Replacing p_i and p_{-i} given in Eq.(3.33) into N_B^o gives

$$N_B^o = \frac{(t - \beta - (f_B^{a*} + h_B^c\rho(v^*) - h_A^n\rho(0))/3)}{2(t-\beta)}.$$

Since $f_B^{a*} = h_B^n\rho(0) - h_B^c\rho(v^*)$, we have that $N_B^o = N_B^n$. Therefore, the profit of the cloud service provider if only bank B joins the cloud equals

$$\pi_C^o = \Phi^o N_B^n - C_c(s_c),$$

where $N_B^n = N_B^o$ represents the demand of bank B when both banks are independent, and $\Phi^o = f_B^{a*} - h_B^c L_c(v^*)$ is the margin of the cloud service provider.

Suppose that the cloud service provider serves both banks. Replacing p_i given by Eq.(3.13) with $z = 1$ and $v = v^*$ into π_C^c given in Eq.(3.5), if banks become compatible, the cloud service provider makes a profit equal to

$$\pi_C^c = 2f^{c*} + (f_A^{a*} - h_B^c L_c(v))N_B^c + (f_A^{a*} - h_A^c L_c(v))N_A^c - C_c(s_c).$$

Since the market is covered, we have $N_B^c = 1 - N_A^c$. This implies that:

$$\pi_C^c = 2f^{c*} + f_A^{a*} - h_B^c L_c(v) + (h_B^c - h_A^c)L_c(v)N_A^c - C_c(s_c),$$

with $f_A^{a*} = h_A^n \rho(0) - h_A^c \rho(v^*)$. Replacing for $\Phi^o = f_B^{a*} - h_B^c L_c(v^*)$ gives:

$$\pi_C^c = 2f^{c*} + f_A^{a*} - f_B^{a*} + \Phi^o + (h_B^c - h_A^c)L_c(v)N_A^c - C_c(s_c).$$

Since $h_B^c - h_A^c = \theta(h_B^n - h_A^n)$, we find that:

$$\pi_C^c = \Phi^c + \Phi^o - C_c(s_c),$$

where

$$\Phi^c \equiv 2f^{c*} + f_A^{a*} - f_B^{a*} + \theta(h_B^n - h_A^n)N_A^c L_c(v^*). \tag{3.39}$$

Therefore, the profit of the cloud service provider is positive only if $\Phi^o \geq -\Phi^c$. Finally, we define the difference of the cloud service provider's profit if it serves both banks and only bank B as:

$$\Delta\pi_C = \Phi^c + \Phi^o(1 - N_B^n).$$

Since $N_A^n = 1 - N_B^n$, we have $\Delta\pi_C \geq 0$ if and only if $N_A^n \Phi^o \geq -\Phi^c$.

Since $\theta\rho(v^*) \leq \rho(0)$, the sign of Φ^c is ambiguous. We remark that $\partial\Phi^c/\partial\beta = \partial f_c^*/\partial\beta$, because Φ^c only depends on β through f_c^*, and $\partial f_c^*/\partial\beta > 0$ from Assumption (A1). Therefore, Φ^c is increasing with β. Since $\Phi^c|_{\beta=0} = \theta N_A^c L_c(v^*) - \rho(0) + \theta\rho(v^*)$, we have that $\Phi^c|_{\beta=0} < 0$ if and only if $\theta < \theta_1$ with $\theta_1 \equiv \rho(0)/(N_A^c L_c(v^*) + \rho(v^*))$. Therefore, Φ^c given in Eq.(3.39) is negative if and only if $\theta\rho(v^*) < \rho(0)$, $\beta \leq \beta_1$ and $\theta < \theta_1$, with β_1 the solution of $\Phi^c(\beta) = 0$ and θ_1 the solution of $\Phi^c|_{\beta=0} = 0$. Otherwise, it is positive.

To conclude, the cloud service provider chooses to outsource only to bank B if $\Phi^c < -N_A^n \Phi^o$, when $\Phi^o > 0$, and it outsources to both banks either if $\Phi^c > -N_A^n \Phi^o$ when $\Phi^o > 0$, or if $\Phi^o + \Phi^c > 0$ when $\Phi^o \leq 0$. Finally, the cloud service provider remains inactive if $\Phi^o < \min\{0, -\Phi^c\}$.

Suppose that banks choose the same level of security at stage 2. Therefore, Φ^c given in Eq.(3.39) equals $2f^{c*}$, such that $\Phi^c > 0$. This contradicts the first condition (i.e., $\Phi^c < -N_A^n \Phi^o$). Therefore, no bank joins the cloud alone when banks invest the same amount of security at stage 2.

Appendix 3: Effect of cloud outsourcing on depositor surplus:

We assume that banks choose symmetric prices (see Appendix 4 for the proof). Therefore, banks share the deposit market equally, and the outsourcing has no effect on depositors' transportation costs. Also, this implies that the access fee f_i^{a*} given in Eq.(3.19) is equal to f_{-i}^{a*}.

Given that only a proportion μ of depositors are sophisticated, the average expected utility of a depositor $E(U_i(z))$ equals $u_i(x) - \mu h_i L_d(zv^*)$, with $u_i(x)$ given in Eq.(3.2), and $z = 1$ (resp., $z = 0$) if banks outsource (do not outsource). Replacing for p_i^* given in Eq.(3.13), the average expected utility of a depositor (net of transportation costs) equals

$$E(U_i(0)) = -t + \frac{3\beta}{2} - h_i^n(s_b^n)\rho(0)$$

if both banks do not outsource their payment services, and

$$E(U_i(1)) = -t + \beta - h_i^c(s_b^c)\rho(v^*) - f_i^{a*}$$

if both banks outsource their payment services, with $f_i^{a*} = h_i^n(s_b^c)\rho(0) - h_i^c(s_b^c)\rho(v^*)$ given in Eq.(3.19). Therefore, the effect of outsourcing on depositor surplus equals

$$E(U_i(1)) - E(U_i(0)) = \frac{-\beta}{2} + \rho(0)(h_i^n(s_b^n) - h_i^n(s_b^c)).$$

Replacing for $h_i^n(s_b) = h - \sigma s_b$, depositor surplus is higher when banks outsource (i.e., if $z = 1$) if and only if $\beta/2 \leq \sigma\rho(0)(s_b^c - s_b^n)$, and it is lower otherwise.

Appendix 4 - Uniqueness of the equilibrium at stage 2

We show that the subgame in which banks choose their security investments admits a unique Nash equilibrium which is symmetric. For this purpose, we analyze the best response of bank i given in Eq.(3.22), to s_{-i} the security investment chosen by bank $-i$.

Case A. Interior solution for bank $-i$ ($s_{-i} \in (0, h/\sigma)$). If there exists a Nash equilibrium such that both banks choose interior solutions for security investments, banks' best responses are given by the first-order conditions in Eq.(3.22). Since banks' costs functions are identical, banks' best responses are symmetric and given by

$$\left.\frac{d\pi_i}{ds_i}\right|_{s_i = s_i^*} = 0.$$

This solution s_i^* is interior if and only if $h_i(s_i^*) \in (0, h)$. Since $s_c \leq h/\sigma$, this is equivalent to $s_i^* \in (0, h/\sigma)$.

If banks expect to outsource (i.e., $z = 1$), we have $s_i^* = s_i^{c*}$, with $s_i^{c*} = \sigma\theta\rho(v^*)/3k_b$ from Eq.(3.24). We have $s_i^* > 0$. Also, given that $\theta \in (0, 1)$ and $h > \sigma$ from Assumption (A2), we have $(\sigma/h)s_i^* < (\sigma/h)h\rho(v^*)/3k_b$, which is always lower than 1 from Assumptions (A1) and (A2). Therefore, we conclude that $s_i^* < h/\sigma$.

If banks expect to remain independent (i.e., $z = 0$), we can prove similarly that $s_i^{n*} \in (0, h/\sigma)$, with s_i^{n*} given in Eq.(3.23). Therefore, the symmetric solution given in Eqs.(3.23)-(3.24) constitutes a Nash equilibrium.

Case B. Minimum investment of bank $-i$. Suppose that bank $-i$ chooses not to invest in cyber-security (i.e., it chooses $s_{-i}=0$). Replacing for $h_i(s_i,s_c)=h_i^c(s_i,s_c)$ and $h_{-i}(s_{-i},s_c)=h_{-i}^c(0,s_c)$ in Eq.(3.22) if banks expect to outsource (or for $h_i(s_i,s_c)=h_i^n(s_i)$ and $h_{-i}(s_{-i},s_c)=h_{-i}^n(0)$ if banks expect to be independent), the optimal investment of bank i, denoted by s_i^m in this case, is given by

$$s_i^m=\frac{\sigma\theta\rho(zv^*)(3t-3(1-z)\beta)}{9k(t-(1-z)\beta)-(\sigma\theta\rho(zv^*))^2},$$

with $z=1$ if banks expect to outsource, and $z=0$ and $\theta=1$ if banks expect to be independent. From Assumptions (A1) and (A2), we have $s_i^m\in(0,h/\sigma)$. Therefore, from Case A, the best response of bank $-i$ consists in choosing an interior solution for its security investment. Since $d\pi_{-i}/ds_{-i}|_{(s_i=s_i^m,s_{-i}=0)}>0$, bank $-i$ has an incentive to deviate from the strategy $s_{-i}=0$, and the pair of strategies $(s_i=s_i^m,s_{-i}=0)$ does not constitute a Nash equilibrium. By symmetry, the pair of strategies $(s_i=0,s_{-i}=s_i^m)$ does not constitute a Nash equilibrium neither.

Case C. Maximum investment of bank $-i$. Suppose that bank $-i$ chooses a maximum level of investment in cyber-security (i.e., $s_{-i}=h/\sigma$). Replacing for $h_i(s_i,s_c)=h_i^c(s_i,s_c)$ and $h_{-i}(s_{-i},s_c)=h_{-i}^c(h/\sigma,s_c)$ in Eq.(3.22) if banks expect to outsource (or for $h_i(s_i,s_c)=h_i^n(s_i)$ and $h_{-i}(s_{-i},s_c)=h_{-i}^n(h/\sigma)$ if banks except to be independent), the optimal investment of bank i, denoted s_i^M in this case, is given by

$$s_i^M=\frac{\sigma\theta\rho(zv^*)(3t-3(1-z)\beta-\theta h\rho(zv^*))}{9k(t-(1-z)\beta)-(\sigma\theta\rho(zv^*))^2},$$

with $z=1$ if banks expect to outsource, and $z=0$ and $\theta=1$ if banks expect to be independent. From Assumptions (A1) and (A2), we have $s_i^M\in(0,h/\sigma)$. Therefore, from Case A, the best response of bank $-i$ consists in choosing an interior solution for its security investment. Since $d\pi_{-i}/ds_{-i}|_{(s_i=s_i^M,s_{-i}=h/\sigma)}<0$, bank $-i$ has an incentive to deviate from the strategy $s_{-i}=h/\sigma$, and the pair of strategies $(s_i=s_i^M,s_{-i}=h/\sigma)$ does not constitute a Nash equilibrium. By symmetry, the pair of strategies $(s_i=h/\sigma,s_{-i}=s_i^M)$ does not constitute a Nash equilibrium neither.

To conclude, the only Nash equilibrium at stage 2 is that banks choose symmetric levels of security investments, which are defined by s_i^{c*} in Eq.(3.23) if they join the cloud, and s_i^{n*} given in Eq.(3.23) if they remain independent.

Appendix 5 - Comparison of the private and the public outsourcing decisions:

Condition such that $\widehat{\beta}\le 0$ banks always join the cloud: Replacing for s_i in $\widehat{\beta}$ given in Eq.(3.28), solving for $\widehat{k}_c$ the solution of $\widehat{\beta}(k_c)=0$ gives:

$$\frac{\widehat{k}_c}{k_w}\equiv\frac{\overline{\rho}(v^*)^2}{(\underline{\alpha}l)^2}\frac{(\underline{\alpha}-1)l}{\overline{\rho}(v^*)-\rho(0)}\frac{hk_b-\sigma^2l\widehat{r}_{k1}/4}{hk_b-\sigma^2\theta\rho(v^*)\widehat{r}_{k2}/3},\tag{3.40}$$

where k_w is given in Proposition 2 assumed different from 0, $\widehat{r}_{k1} = ((\theta\underline{\alpha}l)^2 - 1)/(\underline{\alpha} - 1)$ and $\widehat{r}_{k2} = (\theta\overline{\rho}(v^*) - \rho(0))/(\overline{\rho}(v^*) - \rho(0))$.

From Eq.(3.40), private outsourcing occurs for inefficiently high security costs, with respect to first-best level k_w, if and only if $\widehat{k}_c > k_w$, which happens if and only if the product of the three ratios in the right-hand side of Eq.(3.40) are higher than 1. Below, we explain why each ratio may be higher than one.

- i) The first ratio is higher than one if the cloud service provider internalizes more damage than in the first-best because of moral hazard. Indeed, if this is the case, the benefit of security investment by the cloud service provider is more sensitive to its security cost, and $\frac{\widehat{k}_c}{k_w}$ increases.
- ii) The second ratio is higher than one if the change in the damage internalized by firms is lower than in the first-best. In this case, the cloud service provider earns a positive profit for higher levels of security costs than in the first-best.
- iii) The third ratio is higher than one because for a given level of damage, the cloud service provider faces different objectives with respect to the first-best. As we detail in the main text, the remaining differences stem from the vertical relationships, as the banks fail to internalize the effect of their security decisions on other players (the rival bank, the cloud service provider, and myopic depositors), and the cloud service provider do not internalize the effect of its decision to provide its services on the equilibrium security investment of banks.
  If the cloud service provider contributes to all security investments when banks outsource ($\theta = 0$), then the third ratio is equal to $1 + \sigma^2 l/(4hk_b(\underline{\alpha} - 1))$, which is higher than 1, because the cloud service provider under-estimates the ability of independent banks to invest in protection at the equilibrium.

Comparison of first-best and second-best outsourcing decision: Recall that the total social damage is given by $L(v) = \alpha(v)l + zK(v)$, with $K(\underline{v_c}) = 0$. Replacing for s_c^* given in Eq.(3.25) and for s_b^{c*} given in Eq.(3.24) into Eq.(3.28), we find that

$$\widehat{\beta} = h(\overline{\rho}(v^*) - \rho(0)) - \sigma^2(\frac{(1-\theta)^2\overline{\rho}(v^*)^2}{2k_c} + \theta\rho(v^*)\frac{\theta\overline{\rho}(v^*) - \rho(0)}{3k_b}).$$

Therefore, replacing for β^w given in Eq.(3.29), we find that

$$\begin{aligned}\beta^w - \widehat{\beta} &= h(2(\underline{\alpha} - 1)l - \overline{\rho}(v^*) + \rho(0)) - \sigma^2\frac{(1-\theta)^2}{2k_c}(2(\underline{\alpha}l)^2 - \overline{\rho}(v^*)^2) \\ &\quad -\frac{\sigma^2}{k_b}(\frac{\theta^2(\underline{\alpha}l)^2 - l^2}{2} - \frac{\theta\rho(v^*)(\theta\overline{\rho}(v^*) - \rho(0))}{3}).\end{aligned}$$

Appendix 6 - Effect of the liability of the cloud service provider on investments in cyber security:

Effect on banks' investments: For $\gamma \in \{\gamma_b, \gamma_d\}$, the derivative of s_b^{c*} in Eq.(3.24) with respect to γ is given by

$$\frac{ds_b^{c*}}{d\gamma} = \frac{\sigma\theta}{3k_b}\left(\frac{\partial\rho(v^*)}{\partial\gamma} + \frac{\partial\rho(v)}{\partial v}\frac{\partial v^*}{\partial\gamma}\bigg|_{v=v^*}\right).$$

Replacing for $\epsilon_\rho^v(v^*) = (\partial\rho(v)/\rho(v))/(\partial v/v)|_{v=v^*}$ the elasticity of $\rho(v)$ with respect to v evaluated at $v = v^*$, this expression is equivalent to

$$\frac{ds_b^{c*}}{d\gamma} = \frac{\sigma\theta}{3k_b}\left(\frac{\partial\rho(v^*)}{\partial\gamma} + \epsilon_\rho^v(v^*)\frac{\partial v^*}{\partial\gamma}\frac{\rho(v^*)}{v^*}\right).$$

From Eq.(3.15), $\partial\rho(v^*)/\partial\gamma_b = -q(v^*)$, and $\partial\rho(v^*)/\partial\gamma_d = -\mu q(v^*)$. Also, applying the implicit function theorem on Eq.(3.11), we have $\partial v^*/\partial\gamma > 0$ from Assumption (A2).

To conclude, we have $ds_b^{c*}/d\gamma_b < 0$ if $q(v^*) > \epsilon_\rho^v(v^*)(\partial v^*/\partial\gamma)\rho(v^*)/v^*$, and $ds_b^{c*}/d\gamma_b \geq 0$ otherwise. Similarly, $ds_b^{c*}/d\gamma_d < 0$ if $\mu q(v^*) > \epsilon_\rho^v(v^*)(\partial v^*/\partial\gamma)\rho(v^*)/v^*$, and $ds_b^{c*}/d\gamma_d \geq 0$ otherwise.

Effect on the cloud service provider' investments: For this purpose, using $l = l_b + l_d$, we rearrange $\rho(v^*) = \alpha(v^*)l - (1-\mu)L_d(v^*) - L_c(v^*)$ in Eq.(3.25), such that

$$s_c^*(v^*) = \sigma(1-\theta)\frac{\alpha(v^*)l - (1-\mu)L_d(v^*) + K(v^*)}{k_c}, \tag{3.41}$$

where $\alpha(v^*)l$ represents the total damage in the economy when banks join the cloud.

For $\gamma \in \{\gamma_b, \gamma_d\}$, the derivative of s_c^* in Eq.(3.41) with respect to γ is such that

$$\frac{ds_c^*}{d\gamma} = \frac{\sigma(1-\theta)}{k_c}\left(\frac{\partial\rho(v^*)}{\partial\gamma} + \frac{\partial L_c(v^*)}{\partial\gamma} + \frac{\partial\rho(v)}{\partial v}\frac{\partial v^*}{\partial\gamma}\bigg|_{v=v^*} + \frac{\partial L_c(v)}{\partial v}\frac{\partial v^*}{\partial\gamma}\bigg|_{v=v^*}\right).$$

We have $\partial\rho(v^*)/\partial\gamma_b = -q(v^*)$, and $\partial\rho(v^*)/\partial\gamma_d = -\mu q(v^*)$. Also, from Eq.(3.1), $\partial L_c(v)/\partial\gamma_b = q(v^*)$ and $\partial L_c(v)/\partial\gamma_d = q(v^*)$. From Eq.(3.11), at $v = v^*$, we have $\partial L_c(v)/\partial v = 0$. Finally, applying the implicit function theorem on Eq.(3.11), we have $\partial v^*/\partial\gamma > 0$ from Assumption (A2).

Using the definition of $\epsilon_\rho^v(v^*)$ given above, we have $ds_c^*/d\gamma_b > 0$ if $\epsilon_\rho^v(v^*) > 0$, and $ds_c^*/d\gamma_b \leq 0$ otherwise. Similarly, $ds_c^*/d\gamma_d > 0$ if $(1-\mu)q(v^*) > \epsilon_\rho^v(v^*)(\partial v^*/\partial\gamma)\rho(v^*)/v^*$, and $ds_c^*/d\gamma_d \leq 0$ otherwise.

Appendix 7 - Comparison of outsourcing decision when the government does not decide on security investments :

Replacing for s_c^* given in Eq.(3.25) and for s_b^{c*} given in Eq.(3.24) into W_c given in Eq.(3.9), and for s_b^{n*} given in Eq.(3.23) into W_n given in Eq.(3.7), the cloud service provider makes a positive profit when both banks join the cloud if and only if $\beta > \max\{0, \overline{\beta}_w\}$, with

$$\overline{\beta}_w \equiv 2h(\alpha(v^*) - 1)l - \sigma^2 \frac{(1-\theta)^2\overline{\rho}(v^*)}{k_c}(2\alpha(v^*)l - \overline{\rho}(v^*))$$
$$-2\sigma^2(\frac{\theta^2\alpha(v^*)\rho(v^*) - \rho(0)}{3k_b}l + \frac{(\rho(0))^2 - (\theta\rho(v^*))^2}{3k_b}).$$

Replacing for $\widehat{\beta}$ given in Eq.(3.28) gives:

$$\overline{\beta}_w - \widehat{\beta} \;=\; h(2(\underline{\alpha} - 1)l - \overline{\rho}(v^*) + \rho(0)) - \sigma^2 \frac{(1-\theta)^2\overline{\rho}(v^*)}{2k_c}(4\underline{\alpha}l - 3\overline{\rho}(v^*))$$
$$-\sigma^2(\frac{\theta^2\rho(v^*)(6\alpha(v^*)l - 2\rho(v^*) - 3\overline{\rho}(v^*))}{9k_b} - \frac{\rho(0)(6l - 3\theta\rho(v^*) - 2\rho(0))}{9k_b}).$$

Appendix 8 - Public cloud infrastructure

With the same timing as in our setting: In this Appendix, we denote by $\underline{v} = (1-\theta)\underline{v_c}$ the amount of information hidden by the public cloud service provider. We first show that in our setting, if the regulator is able to set access and compatibility fees, banks' investments do not change. At stage 3, if both banks outsource and they are compatible, social welfare is independent from the access fee. In addition, the setting of the compatibility fee by the regulator is also indeterminate. Therefore, the regulator may set any compatibility fee $f^c \in (0, f^{c*})$, with f^{c*} in Eq.(3.17) the maximum compatibility fee set by the private cloud service provider, and any access fee $f^a \in (0, \min\{f_A^{a*}, f_B^{a*}\})$, with $f_A^{a*} = h_A^n\rho(0) - h_A^c\rho(v^*)$.

Following Appendix 2 - Case B, assume now that only bank $-i$ outsources. The regulator discloses all information in case of incident, such that the damage in case of attack on bank $-i$ equals $\underline{\alpha}l$. Thus, the regulator maximizes

$$W^o = \beta(N_i^o)^2 + \beta(N_{-i}^o)^2 - \int_0^{N_i^o} tx\,dx - \int_{N_{-i}^o}^1 t(1-x)\,dx - h_i^n N_i^o l - h_{-i}^c N_{-i}^o \underline{\alpha} l\ ,$$

with N_i^o and N_{-i}^o given in Eq.(3.30) the respective demands of bank i and bank $-i$ when only bank $-i$ outsources.

Differentiating W^o with respect to f^a, we find that W^o is increasing with f^a if and only if $f^a < f_1^a$, with

$$f_1^a \equiv h_i^n\rho(0) - h_{-i}^c\rho(\underline{v}) - 3(t-\beta)\frac{t + l(h_i^n - h_{-i}^c\underline{\alpha})}{t - 2\beta}$$

if $t \neq 2\beta$, and $\delta(W^o)/\delta f = -(1/3 - l(h^c_{-i}\underline{\alpha} - h^n_i)/6\beta$ otherwise.

Following Appendix 2 - Case B, the regulator is not constrained by banks' incentives if and only if $f^a_1 \in (f^a_i, f^a_{-i})$, with $f^{a*}_i = h^n_i\rho(0) - h^c_i\rho(v^*)$. Denoting $H = -\,3(t+l(t-\beta)(h^n_i - h^c_{-i}\underline{\alpha})/(t-2\beta)$, we have $f^a_i - f^a_1 = -\,H + \rho(\underline{v})(h^c_i - h^c_{-i})$ and $f^a_i - f^a_1 = -\,H + \rho(0)(h^n_i - h^n_{-i})$. Given that $h^c_i - h^c_{-i}$ and $h^n_i - h^n_{-i}$ are of the same sign, the regulator is always constrained by the necessity to provide one bank with the incentive to outsource.

Therefore, if $f^{a*}_{-i} \geq f^{a*}_i$ and $\partial W^o/\partial f^a > 0$, the regulator is constrained by condition (C1b) in Appendix 2, and it sets an access fee equal to f^{a*}_{-i}. If $f^{a*}_{-i} \geq f^{a*}_i$ and $\partial W^o/\partial f^a < 0$, the regulator is constrained by condition (C2b) in Appendix 2, and it sets an access fee equal to f^{a*}_i. Finally, if $f^{a*}_{-i} < f^{a*}_i$, the regulator cannot outsource to bank $-i$ only. In both cases where the regulator can outsource to bank $-i$ only, banks' profit are symmetric (see conditions (C1b)-(C2b)). From Appendix 3, banks set symmetric security investment in these cases, such that $f^{a*}_{-i} = f^{a*}_i$ at the equilibrium of the game, and the regulator never outsources to one bank only.

With a different timing (Fees and banks' investments in security chosen at stage 2): We assume in this section that the regulator only provides a public infrastructure if it delivers a compatibility service. We first detail banks' investments at Stage 2, before considering the regulator's choice of fees.

At Stage 2, the security investment of banks remain equal to our main setting if banks do not outsource, i.e., it equals $s^{n*}_b = \sigma\rho(0)/3k_b$ given in Eq.(3.23). Also, if banks outsource, but do not use the compatibility service, the profit of bank i equals π^{st}_{-i}, which is obtained by setting $v = \underline{v}$ and $z = 0$ in π_i given in Eq.(3.14), such that it is independent from any access fee, and it equals $s^{st*}_b = \sigma\theta\rho(\underline{v})/3k_b$, which is s^{c*}_b in Eq.(3.24), with $v^* = \underline{v}$.

The security investment of banks may depend on the fees set by the regulator in two cases. Let s^{sc*}_i and s^{sc*}_{-i} the investment decided by banks i and $-i$, respectively, when both banks outsource and they use the compatibility service, with $s^{sc*}_{-i} \leq s^{sc*}_i$. Also, let s^{o*}_i and s^{o*}_{-i} banks' investments when only one bank $-i$ uses the storage service.

At stage 2, the regulator sets the compatibility and access fees, with banks' security investments given above. Replacing for symmetric $s_i = s^{st*}_b$ and $s_{-i} = s^{st*}_b$ in π^{st}_{-i} and solving the constraint (C1a) in Appendix 2 with respect to f^c, we find that the maximum compatibility fee such that bank i uses the compatibility service is such that $\pi^c_i(f^c_i, s^{sc*}_i, s^{sc*}_{-i}) = \pi^{st}_i(s^{st*}_b)$, and it equals

$$f^c_i = \frac{\beta}{2} + \frac{((\Delta h^{sc})\rho(\underline{v}))^2}{18t}) - \frac{(\Delta h^{sc})\rho(\underline{v})}{3} + C_b(s^{st*}_b) - C_b(s^{sc*}_i),$$

with $\Delta h^{sc} = h^c(s^{sc*}_i, s_c) - h^c(s^{sc*}_{-i}, s_c)$. We have $f^c_i \leq f^c_{-i}$ if and only if

$$(s^{sc*}_i - s^{sc*}_{-i})(3k_b(s^{sc*}_i + s^{sc*}_{-i}) - 4\sigma\theta\rho(\underline{v})) \geq 0,$$

and $f_i^c > f_{-i}^c$ otherwise.

Replacing for $f^c = f_i^c$ in $\pi_i^c(f_i^c, s_i^{sc*}, s_{-i}^{sc*})$, and using $\pi_i^o(s_i^{o*}, s_{-i}^{o*})$ defined in Appendix 2 with $s_i = s_i^{o*}$ and $s_{-i} = s_{-i}^{o*}$, the constraint (C2a) for bank i is equivalent to $f_i^a \in (\underline{f_i^a}, \overline{f_i^a})$, with

$$\underline{f_i^a} = h_i^o\rho(0) - h_{-i}^o\rho(\underline{v}) - 3(t-\beta)(1 - \sqrt{1 + k(s_i^{o*} - s_b^{st*})(s_i^{o*} + s_b^{st*})/(t-\beta)}).$$

If both banks outsource and use the compatibility service, at the Nash equilibrium, bank i maximizes $\pi_i^c(f_i^c, s_i^{sc*}, s_{-i}^{sc*})$ with respect to s_i^{sc*}. By definition of f_i^c, $\pi_i^c = \pi_i^{st}(s_b^{st*})$ such that the security investment of bank i is indeterminate. Replacing for $f^c = f_i^c$ in $\pi_{-i}^c(f_i^c, s_i^{sc*}, s_{-i}^{sc*})$, the profit of bank $-i$ equals

$$\pi_{-i}^c = \frac{t-\beta}{2} + \frac{2\Delta h^{sc}}{3}\rho(\underline{v}) + C_b(s_b^{st*}) - C_b(s_i^{sc*}) - C_b(s_{-i}^{sc}),$$

such that

$$s_{-i}^{sc*} = \sigma\theta\frac{2\rho(\underline{v})}{3k_b}.$$

Replacing for s_{-i}^{sc*} given above, the equilibrium condition such that the regulator indeed sets f_i^c (i.e., $f_i^c \leq f_{-i}^c$) can be rewritten as $(3k_b s_i^{sc*} - 2\sigma\theta\rho(\underline{v}))^2 \geq 0$, which is true for all s_i^{sc*}. Therefore, the situation where both banks outsource and use the compatibility service constitutes a subgame Nash equilibrium.

Conclusion

Conclusion

Summary of the results

In this dissertation, we have studied from a theoretical and an empirical perspective the consequences of three recent changes in the banking industry on consumers' welfare.

In the first chapter (*Bailout policies when banks compete with switching costs*), we showed that the government protection strengthens competition before the realization of liquidity shocks, because it insures banks against the risk to be unable to benefit from their initial investments in market shares. This effect holds as long as borrowers are myopic, and if the public support does not mostly prevent banks from enjoying future monopoly rents.

However, bailouts may increase interest rates ex post, because the survival of competing banks and switching costs enable banks to take advantage of strategic complementarities and price discrimination to set high interest rates when switching costs are high. As a consequence, bailout policies can decrease consumer surplus ex post. More precisely, we underline that bailout policies generate heterogeneous effects on borrowers' surplus, between borrowers who would have lost access to credit, those who can switch bank, and finally those who stay within the same bank whatever the bailout policy, and thus who only support higher interest rates.

Finally, bailout policies may worsen welfare ex post, because price-discrimination generates inefficiencies in the allocation of credit. Overall, the effect of bailout policies on social welfare depends on banks' financial constraints, on the profitability of credit-constrained projects, and on the level of switching costs.

The second chapter, entitled *Branch closures and access to credit: do severed relationships harm borrowers?*, studies the access to credit of French firms which experienced a closure of their bank branch. Using a combination of matching and difference-in-differences, we show that borrowers from a closed branch benefit from a relative increase in their amount of credit with respect to similar borrowers. After two years, these borrowers hold 6% more credit. This effect is robust to additional restrictions on our matched sample and to the inclusion of additional fixed effects and control variables, and it is homogeneous with respect to borrowers' size and to the number of their banking relationships. As an exception, riskier borrowers do not experience any change in their amount of credit.

This effect of branch closure is supplied by the receiving branch as well as by competing branches, and it does not apply when the branch closure follows a merger of its bank. All these elements suggest that branch closures represent an opportunity for borrowers to either renegotiate their credit conditions, or to search of a new lender.

Finally, and in line with the previous interpretation, the positive effect of branch closure disappears in towns where rival branches to the closed branch are under-represented. This result holds when we focus on rural areas, or when we include branches from neighbor towns. This highlights that the ability of borrowers to take advantage of their branch closure depends on local credit competition.

The third chapter (*Cyber security and cloud outsourcing of payments*) focuses on banks' incentives to outsource their payment systems to a cloud service provider, in the presence of cyber risk. We show that the outsourcing may become welfare-improving because of cyber risk. Indeed, the centralization of payment security in the perimeter of the cloud avoids a duplication of security costs among banks.

In line with the literature on network effects, banks are biased towards excessive outsourcing when cyber risk is absent. However, cyber risk may either limit or increase banks' incentives to over-outsource, depending on the failures in the vertical relationships of banks with the cloud service provider and with their depositors.

Among these failures, we decompose the respective role played by the timing of the investment and pricing decisions, the presence of moral hazard, and the presence of naive depositors regarding cyber risk. Depending on these effects, banks may either over-outsource or under-outsource in th presence of cyber risk.

First, the long-term nature of security investments imply that the cloud service provider does not internalize the effect of its pricing on banks' investments. Because of this timing, it may therefore over-estimate banks' security benefits from outsourcing, and it offers its services too often compared to first-best. This effect increases the bias towards over-outsourcing. Second, banks' investment incentives are distorted by the ability of the cloud service provider to hide some cyber-incidents to banks. This gives banks incentives to over-invest, in order to protect themselves from the additional damage caused by under-reporting of cyber incidents. However, banks also benefit from the under-reporting of cyber incidents, as this enables them to avoid becoming liable towards their depositors.

Thus, the moral hazard effect may either reinforce or weaken the bias towards excessive outsourcing caused by network externalities. Third, the cloud service provider does not internalize the impact of banks' expected damage on competition for depositors. Finally, neither the banks nor the cloud service provider internalize the expected losses incurred by the naive depositors.

We conclude the chapter by discussing how the liability regime for cyber incidents, the ability of a judge to separate the responsibilities of each firm before cyber incidents occur. Increasing firms' liability to depositors helps to alleviate these failures, but split responsibilities in case of incident has opposite effects on the security investments of the cloud service provider and of banks. Finally, we discuss the impact of a public infrastructure for payment systems on payment system security and banks' outsourcing decisions.

Policy implications and research perspectives

In the following, we derive some policy implications of our results that we did not already mentioned in the chapters, and we suggest avenues for complementary research.

The result that bailout policies strengthens banking competition before financial shocks calls for a separation between supervision and competition authorities, as long as bailout policies remain an important tool to promote stability. Indeed, in my model a supervision authority with a competition mandate would face mixed incentives to prevent lenient bailout policies from saving banks. In general, the argument in favor of a separation between competition and supervision authorities underlines the subordination of competition goals to stability measures when the two functions are integrated. On the contrary, we highlight that the incentives of a supervision authority could be weaken under a dual mandate.

However, if market stability can be implement through other resolution tools than bailouts, the objectives of supervision and competition may converge. A necessary condition is that the resolution policy preserves banks' incentives to invest. For instance, banks' shareholders may have very few incentives to promote competition when bail-in or bridge banks policies are credible. On the contrary, the separation between a good bad and a bad bank, or the expected sale of market-based activities, may preserve banks' incentives to invest in the credit market. A more precise analysis of the competitive effects of new resolution tools, however, remains to be done.

A result common to chapters 1 and 2 is that the severance of the relationship between banks and borrowers can sometimes benefit borrowers. In chapter 1, the reason for the effect lies in the disappearance of strategic complementaries among banks. In chapter 2, borrowers appear to be able to take advantage of local competition once the branch closed. This suggests that transaction costs remain an important market failure in credit markets, as well as a source of bank rent. Therefore, it would be interesting to understand if the effect of branch closures decreases with the fintech presence. A positive answer would suggest that fintech firms reduce transaction costs for all borrowers on a local market, and that they benefit mostly to borrowers with a disrupted banking relationship otherwise.

In chapter 3, we underline that the vertical relationship between banks and a cloud service provider is a source of multiple failures, which distort security investments away from first-best. This vertical relationship, where the cloud service provider offers specific IT solutions to banks, is also the market structure considered by current regulation of third-party providers (e.g., *the Digital Operational Resilience Act*), because it poses the most direct threat to financial stability. However, cloud companies and banks also create relationships where the bank provides its infrastructure of payment. Recent examples of these partnerships include Apple Pay with Goldman, or Google Pay with Citigroup and Stanford Federal Credit Union. It remains unclear how possible cross-services between banks and cloud companies would affect the ability of fees to provide minimum incentives to invest in security. However, our analysis in a one-sided relationship strikes a note of caution. Also, the inability of BigTech credit cards, as opposed to banks in our analysis, to benefit from their own in-house payment system, suggests that the fees paid to banks may be even less sensitive to cyber risk.

Résumé : Cette thèse étudie, d'un point de vue théorique ou empirique, les conséquences sur la concurrence bancaire et sur le bien-être de trois changements récents dans l'industrie bancaire. Le premier chapitre s'intéresse aux effets des politiques de sauvetage public, lorsque les emprunteurs supportent des coûts de changements de banque. La protection de l'État intensifie la concurrence ex ante si elle garantit un accès suffisant aux liquidités. Cependant, le sauvetage peut être indésirable ex post, car la survie de concurrents et les coûts de changements permettent une discrimination par les prix source d'inefficacités dans l'allocation du crédit. Le second chapitre étudie l'accès au crédit des entreprises françaises suite à la fermeture de leur agence bancaire. Après deux ans, ces entreprises détiennent 6% de plus de crédit à cause de la fermeture. Cet effet opère à la fois dans la nouvelle agence et auprès d'agences concurrentes, mais il n'a lieu que dans des communes bien dotées en agences. Le troisième chapitre porte sur les incitations des banques à externaliser leurs systèmes de paiement sur le cloud, en présence de risque cyber. Le risque cyber peut rendre l'externalisation souhaitable. Il peut aussi limiter, ou au contraire renforcer, les incitations des banques à trop externaliser, en raison de défaillances dans leurs relations verticales avec le cloud et avec leurs déposants. Accroître les responsabilités civiles envers les déposants, ou définir le périmètre de responsabilité de chaque acteur en cas d'incident, peut limiter ces défaillances.

Descripteurs : concurrence bancaire, effets de réseau, coûts de changement, agence bancaire, sauvetage public, externalisation, risque cyber

Abstract: This dissertation consists of theoretical and empirical studies on the consequences of three recent changes in the banking industry on banking competition and welfare. The first chapter examines the effects of bailout policies when borrowers face switching costs. The government protection strenghtens competition ex ante if it guarantees a sufficient liquidity support to banks. However, bailouts may not be welfare-improving ex post, because the survival of competing banks and switching costs enable banks to price-discriminate, which generates inefficiencies in the allocation of credit. The second chapter studies the access to credit of French firms which experienced a closure of their bank branch. After two years, these borrowers hold 6% more credit because of the closure. This effect is supplied by the receiving branch as well as by competing branches, but it only applies in areas with dense branch networks. The third chapter focuses on banks' incentives to outsource their payment systems to a cloud service provider, when cyber-risk exists. Outsourcing may become welfare-improving because of cyber-risk. Cyber-risk can also limit or increase banks' incentives to over-outsource, depending on the failures in the vertical relationships of banks with the cloud service provider and with their depositors. Increasing firms' liability to depositors, or setting their perimeter of responsibility before cyber incidents occur, may alleviate these failures.

Keywords: banking competition, network effects, switching costs, bank branch, bailout, outsourcing, cyber risk