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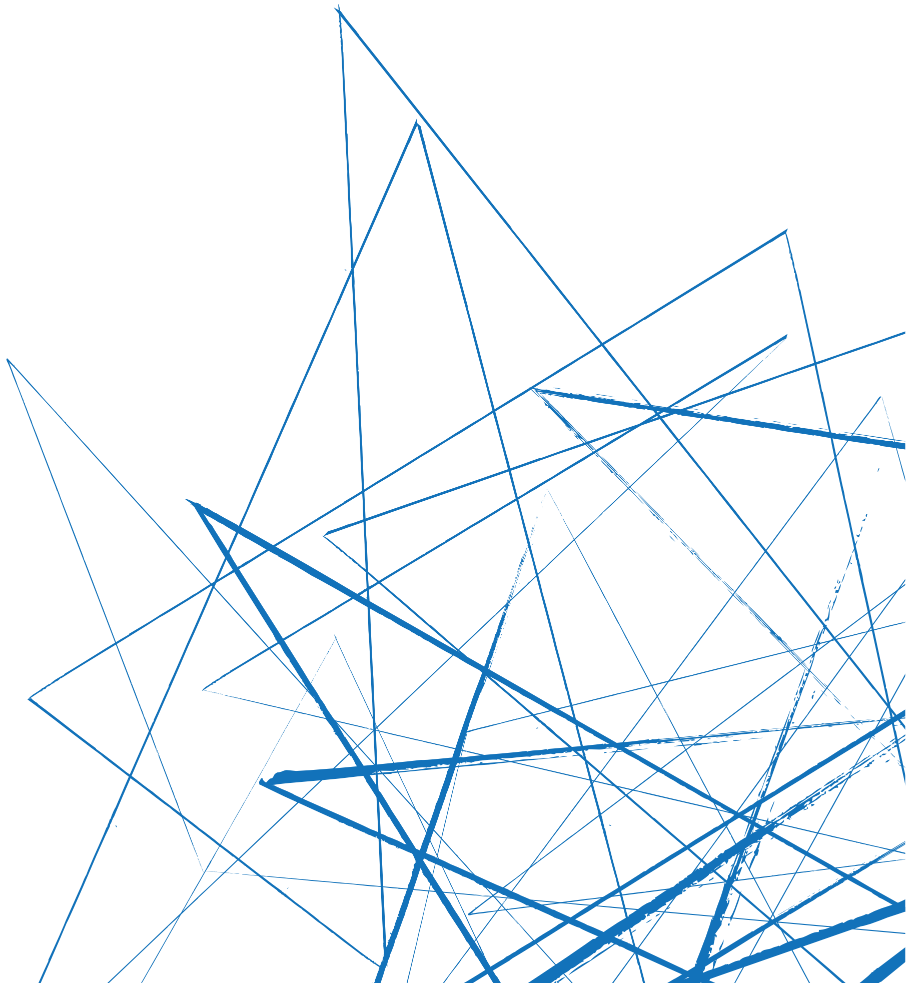

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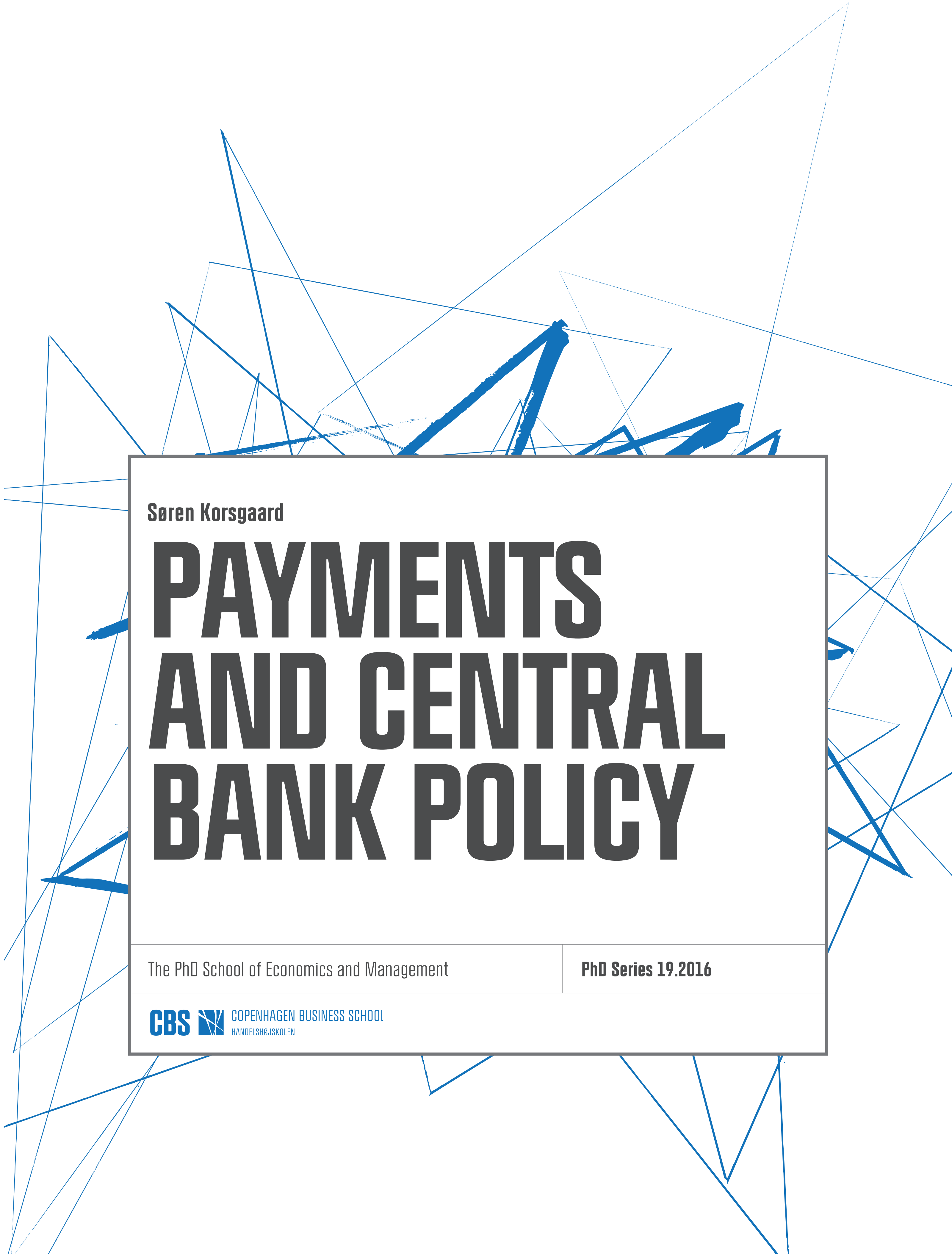

Søren Korsgaard

PAYMENTS AND CENTRAL BANK POLICY

The PhD School of Economics and Management

PhD Series 19.2016

CBS COPENHAGEN BUSINESS SCHOOL
HANDELSHØJSKOLEN

Payments and Central Bank Policy

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PhD School in Economics and Management

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Preface

This thesis consists of three chapters. The first, "Paying for Payments", examines the role of interchange fees in payment card networks. The second, "Bank Liquidity and the Interbank Market" (co-authored with Mikael Reimer Jensen), investigates how banks' liquidity holdings at the central bank affect outcomes in the money market. The third, "Collateralized Lending and Central Bank Collateral Policy", considers the emergence of credit constraints under collateralized lending, and how central banks use collateral policy to mitigate these constraints. While the chapters can be read independently, they share common themes. Each chapter is concerned with payments in one way or another, each is concerned with the efficiency of market outcomes, and, to the extent that there is scope for improving these outcomes, each discusses the appropriate role for policy, in particular central bank policy.

I would like to acknowledge the support of Danmarks Nationalbank which has provided funding for my PhD studies at Copenhagen Business School. I am grateful to my supervisors Lasse Heje Pedersen and David Lando for advise and feedback and for creating an excellent research environment at the Center for Financial Frictions (FRIC). A number of other people deserve special thanks. These include Kristian Kjeldsen from Danmarks Nationalbank, who encouraged me to pursue the degree, Javier Suarez, who hosted me at CEMFI in the autumn of 2014, Peter Norman Sørensen, who took part in my closing seminar, my good colleagues at Danmarks Nationalbank, other faculty and fellow PhD students for helpful discussions and, not least, my family.

Chapter summaries in English and Danish

This section contains summaries of the three chapters of the dissertation in English and Danish.

Chapter 1

English summary. When a consumer pays using a payment card, an interchange fee is typically transferred from the merchant's bank to the consumer's bank. Even though interchange fees are commonly agreed upon collectively by banks, they do not function as ordinary monopoly prices. Interchange fees can enhance welfare, and in conventional models of interchange fees it is unclear whether the interchange fee set by banks is too high or too low relative to the social optimum. Even if it were biased, the optimal fee would depend on unobservable quantities such as consumer preferences, rendering it of little practical value to a regulator. Taken together, these findings suggest that the case for regulating interchange fees is weak.

I examine a model of interchange fees in which the above conclusions are reversed. This occurs in the special, but empirically relevant case in which banks do not charge consumers transaction fees. In that case privately set interchange fees exceed the social optimum, resulting in too few card payments. Moreover, the socially optimal fee depends only on the difference in marginal cost of producing card and cash payments. Given adequate data on the cost of producing payments, it can therefore be calculated by a regulator and used as a benchmark. I also analyze a number of related policy issues, for example the effects of surcharging. In my model, surcharging does not "neutralize" the effect of interchange fees, as is often found in the related literature.

Dansk resumé. Når en forbruger betaler med et betalingskort, overføres et interbankgebyr typisk fra forretningens bank til forbrugerens bank. Selv om interbankgebyrer ofte fastsættes kollektivt af banker, fungerer de ikke som ordinære monopol-priser. Interbankgebyrer kan forøge velfærd, og i konventionelle modeller af interbankgebyrer er det uklart, om det interbankgebyr,

som bankerne fastsætter, er for højt eller for lavt i forhold til det socialt optimale gebyr. Det optimale gebyr afhænger endvidere af forbrugerpræferencer, som ikke er observerbare. Det vil derfor være vanskeligt at regulere interbankgebyrer, selv hvis de systematisk afveg fra det socialt optimale. Samlet set gør disse betragtninger, at der er ikke noget klart belæg for at regulere interbankgebyrer.

Jeg beskriver en model af interbankgebyrer, hvor ovenstående konklusioner ikke gælder, snarere det modsatte. Det sker i det særlige, men empirisk relevante tilfælde, hvor banker ikke afkræver forbrugerne transaktionsgebyrer i forbindelse med kortbetalinger. I det tilfælde overstiger interbankgebyrerne det socialt optimale niveau, hvilket resulterer i for få kortbetalinger. Det socialt optimale gebyr afhænger alene af forskellen i de marginale omkostninger ved at producere kort- and kontantbetalinger. Givet tilstrækkelige omkostningsdata vil en myndighed således kunne beregne det optimale interbankgebyr og benytte det som et benchmark. Jeg undersøger endvidere en række andre forhold, herunder effekterne af overvæltning. I min model ”neutraliserer” overvæltning ikke interbankgebyrer, som det ofte ses i den relaterede litteratur.

Chapter 2

English summary. Banks turn to the overnight interbank market to absorb payment shocks. We address whether banks with less central bank liquidity pay higher rates in the money market. While liquidity-constrained banks may be willing to pay higher rates, competition among lenders with surplus liquidity should push down rates in a functioning money market.

The analysis couples data on overnight loans with a measure of bank liquidity. On average, banks in need of liquidity pay only a small premium relative to those with ample liquidity. While the premium is statistically significant, it is trivial from an economic perspective. The liquidity premium is larger when aggregate liquidity is scarce, when liquidity is needed more urgently, and when payment activity is large, but overall the results point to a well-functioning money market.

The link between credit risk and liquidity is examined in some detail. One concern is that our estimates are biased because riskier banks choose to hold more liquidity. We attempt to control for this through various strategies, including the use of fixed effects, differencing, and instrumental variables, and in most cases still find low liquidity premia. Our analysis further suggests that riskier banks are less likely to participate in the money market, but that credit risk seems to play a negligible role for those banks which can access the market. Finally, the analysis sheds light on the role of central banks in shaping money market outcomes. The money market is less active, for example, when central bank facilities are available.

Dansk resumé. Banker benytter interbankmarkedet til at håndtere uventede betalingsstrømme. Vi undersøger, hvorvidt banker med begrænset centralbanklikviditet betaler højere renter i pengemarkedet. Selv om banker i likviditetsnød formentlig er villige til at betale højere renter, burde konkurrence mellem potentielle långivere med overskudslikviditet presse renterne ned i et velfungerende pengemarked.

Analysen knytter lånedata med et mål for bankers likviditet. Banker med begrænset likviditet betaler kun en mindre præmie i forhold til banker med rigelig likviditet. Likviditetspræmien er statistisk signifikant, men økonomisk set ubetydelig. Likviditetspræmien er større, når den samlede likviditet er mindre, når banker har mindre tid til at skaffe likviditet og når den samlede betalingsaktivitet er større. Samlet indikerer resultaterne, at pengemarkedet er velfungerende.

Vi undersøger også sammenhængen mellem kreditrisiko og likviditet. Et potentielt problem er, at risikable banker vælger at holde mere likviditet, hvilket kan påvirke vores estimater. Vi forsøger at kontrollere for dette gennem forskellige metoder, herunder estimation ved brug af såkaldte "fixed effects", ved "differencing" og ved brug af instrumenter. I de fleste tilfælde finder vi fortsat begrænsede likviditetspræmier. Resultaterne tyder endvidere på, at mere risikable banker sjældnere deltager i pengemarkedet, men at kreditrisiko spiller en begrænset rolle for banker med adgang til markedet. Endelig viser analysen, at centralbanker har stor indflydelse på pengemarkedet. Som eksempel er pengemarkedet mindre aktivt, når centralbankfaciliteter er tilgængelige.

Chapter 3

English summary. The chapter has two parts. The first part examines when credit constraints arise under collateralized lending. In the model, banks can either acquire information about the collateral quality of firms prior to lending or lend uninformed based on the expectation of the collateral being adequate. When collateral quality is more uncertain, banks have a strong incentive to acquire information. Firms prefer to avoid this and may seek smaller loans. They use less capital than is feasible given the technology and collateral at hand. They are, in a sense, credit constrained. I show that credit constraints especially afflict firms with less profitable investment projects, even though project and collateral quality are unrelated.

In the second part of the chapter, a central bank is introduced. If few banks verify the actual collateral quality, the economy is more prone to informational shocks which lead to funding withdrawals. However, uninformed lending generally allows firms to use more capital. The central bank uses collateral policy to manage this trade-off by affecting banks' incentives to gather information. When collateral quality is high, firms have access to ample capital, and central banks use collateral policy to induce more information acquisition. If credit constraints arise due to changes in beliefs about collateral quality, on the other hand, central banks allow agents to post lower quality collateral. These findings resemble actual policy in normal times and times of crisis respectively.

Dansk resumé. Kapitlet består af to dele. I den første del undersøges, hvornår kreditklemmer opstår ved långivning mod sikkerhed. I modellen kan banker enten verificere kvaliteten af virksomheders sikkerheder forud for långivningen eller låne mod en forventning om, at sikkerhederne er tilstrækkelige. Når der er mere usikkerhed omkring kvaliteten af sikkerheden, har banker et stærkt incitament til at verificere dens egentlige kvalitet. Virksomheder ønsker at undgå dette og kan reagere ved at ansøge om mindre lån og benytte mindre kapital, end de reelt har mulighed for. De er i den forstand ramt af en slags kreditklemme. Jeg viser, at mindre profitable virksomheder rammes særligt hårdt, selv om deres profitabilitet og kvaliteten af deres sikkerheder er urelaterede.

I den anden del af kapitlet introduceres en centralbank. Hvis få banker verificerer den reelle kvalitet af sikkerhederne, er der større risiko for, at nye informationer får bankerne til at trække kredit tilbage. Omvendt indebærer uinformeret långivning, at virksomheder generelt kan få mere kredit. Centralbanken afvejer disse effekter, og benytter dens sikkerhedsstillelsespolitik til påvirke bankernes incitamenter til at indsamle information. Når den generelle kvalitet af sikkerhederne i økonomien er høj, har virksomheder adgang til rigelig kredit, og centralbanken tilskynder mere indsamling af information. Omvendt tilskynder centralbanken uninformeret långivning, når kreditklemmer opstår, fordi kvaliteten af sikkerhederne skønnes at være ringere. Disse resultater afspejler centralbankers faktiske adfærd i normale og krisetider respektivt.

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Introduction

This thesis consists of three chapters, dealing with interchange fees, the money market, and central bank collateral policy respectively. While seemingly disparate, these topics share some commonality, at least in the minds of central bankers who have traditionally grouped them together in their payment systems or financial stability departments. Logically, the most obvious common denominator is that each topic deals with payments in one way or another. Interchange fees are perhaps the most important prices in the market for retail payment, and the overnight money market is used by banks to absorb payments shocks. Collateral policy is likewise important to the flow of payments, not least because banks occasionally accumulate large intraday payment deficits and borrow from central bank against collateral to fund these (Martin, 2004).

Another shared feature is that policy, not least central bank policy, can have welfare implications in each of these areas. Interchange fees affect whether merchants accept payment cards and whether consumers pay using cash or cards. Since there can be non-trivial differences in the social costs of using certain payment instruments (Schmiedel et al., 2012), the choice of interchange fee has real implications. Central bank actions also influence outcomes in the money market, as evidenced by the experiments with large-scale asset purchases (Bech and Monnet, 2013). Finally, collateral policy has proven a potent monetary tool in its own right (Ashcraft et al., 2010), and central banks have on more occasions used it to affect e.g. the design of securities (Zorn and Garcia, 2011).

The first chapter of the thesis examines the role of interchange fees in payment card networks. When a consumer pays a merchant using a payment card, an interchange fee is transferred from the merchant's bank to the consumer's bank. Interchange fees are typically agreed upon collectively by banks, yet they do not function as traditional monopoly prices due to the two-sided nature of the market for payment instruments (e.g. Evans and Schmalensee, 2005; Rochet and Tirole, 2006; Rysman, 2009). In fact, interchange fees can remedy a problem of costs and benefits being asymmetrically distributed across the consumer and merchant sides of the market. A common argument is that consumers' banks bear the bulk of the cost of producing card payments whereas merchants enjoy most of the benefits by not having to handle cash. A transfer from merchants to consumers, e.g. in the form of an interchange fee, is one way of dealing with this asymmetry.

The existing literature highlights this potential efficiency. It also points out that there is no a priori reason to believe that fees are either too high or too low relative to the social optimum; and even if privately set interchange fees were systemically biased, it would be difficult for a regulator to identify an optimal fee since such a fee will generally depend on the distribution of agents' preferences, which is unobservable.

The seminal paper in the literature is Rochet and Tirole (2002). They consider a model in which privately set interchange fees are, in fact, biased, either equaling or exceeding the social optimum. In their model, this leads to too many card payments being produced. While their model is useful for thinking about the effects of interchange fees, it is also seemingly at odds with country-level data on card usage, which has become available since they wrote their paper. Statistics from the European Central Bank, for example, show card usage to be highest in exactly the countries where interchange fees, due to regulation, have not been applied historically.

In the chapter I consider a model of interchange fees, based on Rochet and Tirole (2002), which may explain this finding. The model is predicated on a simple empirical observation: It is often the case that banks do not charge consumers transaction fees. In practice, payment services are often provided either for free or against fixed, periodical fees. I show that in this special case, the key conclusions from the earlier literature are not only different, but sometimes entirely reversed. Higher interchange fees are associated with less card usage, and banks set interchange fees at or above the social optimum. The upshot is that there will be fewer card payments than is socially optimal. Finally, the socially optimal fee depends only on the difference in marginal cost of producing card and cash payments. Given adequate data on the cost of producing payments, it can therefore be calculated. The paper therefore not only shows that interchange fees are biased, but provides a potential method for regulating fees.

The chapter speaks to an important political discussion. Merchants have long argued that banks set excessively high fees (Wright, 2012), and various countries have introduced caps on interchange fees. In the US, for example, the Federal Reserve has been assigned the task of setting standards for interchange fees, and the European Commission has capped interchange fees at low levels. The chapter also includes analyses of related policy issues, for example the effects of surcharging. Surcharging is sometimes claimed to "neutralize" the effect of interchange fees, but that is not the case in my model. Permitting merchants to surcharge is therefore not a viable substitute to regulating interchange fees.

In the second chapter, we conduct an empirical study of the overnight interbank market prior to, during, and after the financial crisis. Earlier studies of the money market (Furfine, 2001, 2002) generally found the money market to be robust during periods of stress, a conclusion which was tempered somewhat following the crisis (Afonso et al., 2011).

We address whether banks with less central bank liquidity pay higher rates in the money market. While liquidity-constrained banks are willing to pay higher rates, as documented by Fecht et al. (2011) in the context of ECB refinancing auctions, competition among lenders with surplus liquidity should push down rates in a functioning money market. To the extent that banks in need of liquidity pay substantial premia, it could be a sign of market dysfunction.

The analysis couples data on overnight loans, derived from an algorithm akin to that in Furfine (1999), with a novel measure of bank liquidity. Controlling for other factors which are likely to affect money market rates, notably credit risk, we test whether banks with less liquidity pay higher rates. On average, banks in need of liquidity pay only a small premium relative to those with ample liquidity. While this premium is statistically significant, it is trivial from an economic perspective, on the order of less than a single basis point. The liquidity premium is larger when aggregate liquidity is scarce, when liquidity is needed more urgently, and when payment activity is large, but overall the results point to a well-functioning money market.

The link between credit risk and liquidity is examined in some detail. One concern is that riskier banks choose to hold more liquidity, thereby biasing estimates. We attempt to control for this through the use of fixed effects, a differencing strategy, and an instrumental variables approach, and in most cases still find low liquidity premia. There is also a part of the sample period during which money market loans were covered by an explicit government guarantee, effectively removing credit risk, and liquidity premia are also negligible during that period. Overall, our results indicate that riskier banks are less likely to participate in the money market, but credit risk does not appear to have large effects for those banks which are of adequate quality to participate in the market.

Finally, the analysis sheds light on the role of central banks in shaping money market outcomes. The money market is less active when central bank facilities are available, and interest rates also depend on factors such as aggregate payment flows and whether banks can borrow from the central bank.

The third chapter has two parts. The first part examines a model of collateralized lending which based on Gorton and Ordoñez (2014). It addresses the question of when credit constraints, the use of less capital than is feasible given the technology and collateral at hand, arise. I show that credit constraints arise when collateral quality is more uncertain. Interestingly, credit constraints are more pronounced for firms with less profitable investment projects, even though 1) firms are only able to lend because they can post collateral and 2) profitability and collateral quality are completely unrelated.

Banks can either acquire information about the collateral quality of firms prior to lending or lend uninformed. The assumption is that if little information is being gathered in aggregate, the economy is more prone to shocks which lead to funding withdrawals. Uninformed lending, however, also has benefits. There is pooling of firms with good and bad collateral which allows agents with good projects, but bad collateral to obtain credit. In general, uninformed lending allows agents to use more capital than informed lending.

A central bank is introduced in the second part of the paper. Discussions of the appropriate role for central bank collateral policy date back to Bagehot (1873) who discusses how a central bank should respond to a panic. The setting in Gorton and Ordoñez (2014) is a useful starting point for thinking about collateral policy both because it involves collateralized lending and because it features credit constraints whose effects resemble "panics". In the model, the central bank uses collateral policy to affect banks' incentives to gather information. The central bank exploits the fact that banks may have to borrow from the central bank, or alternative hoard liquidity, to be able to make payments. Specifically, it can make a certain degree of information acquisition a prerequisite for collateral eligibility with the central bank.

When collateral quality is high, uninformed lending dominates informed lending, and firms have access to ample capital. In this case, central banks use collateral policy to more induce information acquisition so as to lower the probability of shocks. If credit constraints arise due to changes in beliefs about collateral quality, on the other hand, central banks allow agents to post lower quality collateral. These findings resemble patterns in actual policy. More central banks have used collateral policy to foster transparency in order to limit systemic risks, but during crises collateral policy has effectively encouraged less information-intensive lending.

The model also speaks to other features of collateral policy. For example, it suggests that central banks should give preferential treatment to collateral characterized by high information costs, i.e. information-insensitive assets such as safe debt securities. It also highlights some limitations of collateral policy as a tool, or at least the particular channel of collateral policy under consideration.

Paying for Payments

Abstract

This paper examines the role of interchange fees, transfers from merchants' banks to consumers' banks when card payments take place, when consumers do not face card transaction fees. Without transaction fees, interchange fees work differently than is conventionally assumed. Banks always set interchange fees at or above the social optimum, resulting in too few card payments. There exists an optimal fee which depends only on the cost of producing payments. Finally, surcharging does not neutralize interchange fees. The findings may help explain card usage patterns across countries and have implications for the regulation of interchange fees.

Keywords: Financial regulation; Interchange fees; Payments

JEL-classification: E42; G21; G28

1.1. Introduction

A key role of banks is to provide payment services. The cost of producing these services is non-negligible. Based on a joint study conducted by central banks in 13 European countries, the European Central Bank estimates the real cost of producing payments to be about 1.0 per cent of GDP on average (Schmiedel et al., 2012). More than 70% of the cost relates to the production of cash or card payments, and about half is incurred by banks. In spite of high costs, bank fees often provide weak incentives for consumers to choose efficient payment methods. Consumers often do not pay any fees, or pay flat periodical fees, and then get access to the use of debit cards, online banking, and other payment services. Borzekowski et al. (2008) cite evidence that only 15% of US banks charge consumers for debit card transactions.[1] A similar pattern is found in many European countries.[2]

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[1] The number is based on data from 2004 and covers only PIN-based debit card transactions from which banks, according to the authors, derive less interchange fee revenue than for signature-based transactions. Banks would therefore seem to have an incentive to charge consumers fees for exactly these transactions.

[2] As an example, Jonker (2013) describes the typical fee structure in the Netherlands as follows: "[...] banks call these fees payment package fees. The fees are linked to a payment package including the use of a current account, access to online banking and a debit card which consumers can use for making debit card payments or to use ATMs. Credit cards are provided optionally at extra cost. Consumers do not pay any transaction fees for card payments,

The most important price in the market for card payments is the *interchange fee*. An interchange fee is a fee paid (normally) from the merchant's bank to the consumer's bank when a card transaction take place. In principle, interchange fees can improve welfare, and a simple example illustrates how: Suppose a consumer values the ability to pay by card at 0.5 while a merchant enjoys savings of 1.0 when payment is made by card. If the consumer bank's cost is 0.75, and the merchant bank's cost is 0.25, it is beneficial for the transaction to take place since the total benefit of 1.5 exceeds the total cost of 1.0. However, in the absence of a transfer from merchants or their banks to consumers or their banks, a card transaction may not be feasible since the consumer's bank cannot cover its costs from the consumer.

While interchange fees are potentially beneficial, they have come under scrutiny. Merchants argue that banks set excessive fees (Vickers, 2005; Wright, 2012), and regulators too have grown concerned. Fee levels are typically agreed upon collectively by banks and thus set a lower bound for a merchant's cost of receiving payment by card. In the US, the Durbin Amendment to the Dodd-Frank Act introduced caps on fees, with the Federal Reserve being assigned responsibility for setting regulatory standards; Shy (2014) assesses some effects of the regulation. In 2015, the European Union agreed to a regulation of interchange fees which will cap fees at 0.2% for debit cards and 0.3% in the case of credit cards.[3]

I examine a number of questions of concern to interchange fee regulation: What is the effect of interchange fees on cash and card usage? What is the socially optimal fee, and what information would a regulator need to calculate it? Is there scope for regulation, that is, are privately set fees systematically biased relative to the social optimum? The conventional view has been that interchange fees foster card adoption and so lead to increased card usage, that the socially optimal fee depends on unobservable quantities such as the distribution of consumer preferences for cards relative to cash, making it hard if not impossible for a regulator to identify such a fee, and that there is little basis for regulation of interchange fees. A clear exposition of this view is found in Evans and Schmalensee (2005) who note that "[...] there is a consensus among economists that, as a matter of theory, it is not possible to arrive, except by happenstance, at the socially optimal interchange fee through any regulatory system that considers only costs." These conclusions follow because the market for payment instrument is "two-sided" (Rochet and Tirole, 2006; Rysman, 2009; Weyl, 2010): The benefits enjoyed by consumers depends on the fraction of merchants accepting

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cash withdrawals or cash depositions at the ATM [...] [banks] tend not to make consumers directly aware of the costs associated with their payment behaviour or to provide any incentives towards more cost efficient payment behaviour."

[3] Interchange fees were already capped in 2003 in Australia when The Reserve Bank of Australia mandated a reduction in interchange fees, see e.g. Chang et al. (2005).

cards, and the benefits enjoyed by merchants depends on the fraction of consumers using cards. This sets pricing apart from in one-sided markets. Even if fees are set collectively by banks, the outcome is not monopoly pricing (Schmalensee, 2002; Wright, 2004).

Models of interchange fees generally assume that fees are passed on to consumers in the form of a lower marginal cost of card payments. I consider the case in which consumers do not face transaction fees and show that (1) banks always set an interchange fee which exceeds or equals the socially optimal fee[4], and (2) that total card usage in the economy is declining in interchange fees. Combined, these facts imply that there are too few card payments. (3) I also find a purely cost-based optimal interchange fee, thus providing a means for a regulator to evaluate fee levels. (4) I consider the role of alternatives to interchange fee regulation, for instance permitting merchants to pass on (surcharge) fees to consumers. (5) I discuss conditions under which no transaction fees may emerge as an equilibrium outcome. (6) I illustrate the model using data on the cost of payments.

The model is based on an analytical framework similar to that in Rochet and Tirole (2002, 2011) and Wright (2004, 2012) who extend the original analysis of Baxter (1983). It involves three types of agents: consumers, merchants and banks. Consumers and merchants derive benefits from using cards instead of cash. Consumers choose which merchants to purchase from based on their prices and whether they accept cards. Merchants decide whether to accept payment cards based on the benefits they enjoy, the fees they must pay, and the fraction of consumers preferring to pay by card. Banks face costs related to the production of card and cash payments, and set interchange fees in order to maximize their joint profits which depend on the fraction of consumers and merchants respectively using and accepting cards. The key difference relative to earlier papers is that assumption that consumers do not pay their banks when making payments. An obvious critique of this assumption is that transaction fees are endogenous. In particular, if interchange fees are adequately high, it is in the interest of banks to ensure that their customers pay using cards rather than cash, e.g. by applying negative fees. I therefore devote a section to discussing when zero transaction fees emerge in equilibrium under the weaker condition that card transaction fees must be non-positive. Specifically, it must be the case that (a) interchange fees are relatively low given zero transaction fees and (b) that zero transaction fees are optimal given those interchange low fees. Whether these conditions are satisfied turn out to depend on banks' market power in both consumer and merchant markets.

While data on interchange fee levels is scarce, the existing evidence suggests that the results of the paper are practically relevant, at least in Europe. Börestam and Schmiedel (2011) report that in 2006 four European countries had national card schemes which operated entirely without interchange fees, namely those in Denmark, Finland, Luxembourg and the Netherlands. If high interchange fees were critical to the adoption of payment cards, one might expect weak card adoption in these countries. Consistent with the model, however, Figure 1.1 show that the countries which have historically had payment card schemes without interchange fees also happen to be those in which card usage is greatest.[5] Further supportive evidence can be found in e.g. Arango et al. (2015), who find that weak merchant acceptance play a large role in the use of cash and that changes in consumer rewards have small effects on card usage by consumers, and in Valverde et al. (2016) who find positive effects on card usage and welfare from reductions in interchange fees.

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[4] A similar result can be found in other papers (e.g. Bedre-Defolie and Calvano (2013); Rochet and Tirole (2002); Wright (2012)).

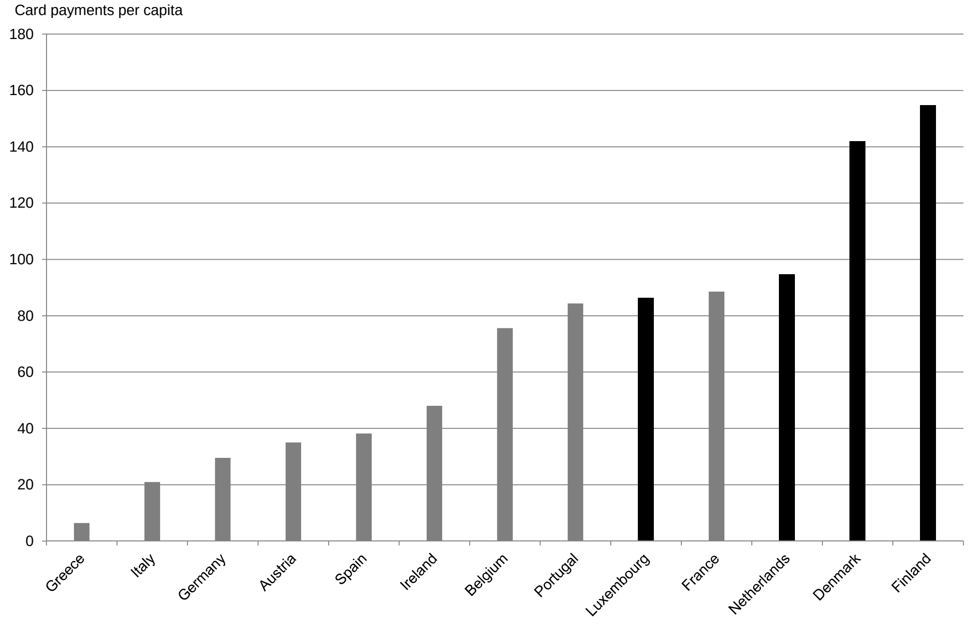

Figure 1.1: Card usage in selected European countries
The figure shows the number of card payments per capita per year in the European countries which were part of the Eurosystem in 2006, plus Denmark. Countries which historically have not had interchange fees are highlighted in black. Source: ECB Statistical Data Warehouse.

I also examine some extensions to the model, most importantly what happens when merchants are permitted to surcharge. In some models, surcharging can "neutralize" the effect of interchange fees (Gans and King, 2003; Zenger, 2011). In my model, surcharging does not neutralize interchange fees. Interchange fee regulation becomes more complicated when surcharging is permitted for at least two reasons. First, it is not straightforward to establish the conditions under which merchants surcharge and, second, there may be multiple equilibria when surcharging is permitted. Empirical studies confirm that surcharging, where permitted, is not uniformly practiced (Bolt et al., 2010; Jonker, 2011). Second, if merchants surcharge, the optimal fee changes. I also conduct a simple numerical illustration of the model based on data from the Danish part of the European Central Bank cost of payment study (Schmiedel et al., 2012). The optimal interchange fee slightly negative. It can be compared to fees obtained by other methods such as the so-called merchant indifference test (Rochet and Tirole, 2011). The fee implied by this test is about 0.2% which, interestingly, is the same figure as in the recent EU regulation.

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[5] There are also examples of countries with interchange fees with relatively high card usage, e.g. England and Sweden, though interchange fees are not particularly high in these countries. In Sweden, moreover, interchange fees are not agreed multilaterally between banks, but bilaterally.

The model best describes the market for debit cards. Credit card holders commonly receive benefits or bonuses, and optimal interchange fees are also different for credit cards (Rochet and Wright, 2010). As for price structure, interchange fees tend to be proportional fees rather than per transaction fees (e.g. Shy and Wang, 2011). The model assumes a linear city model of merchant competition as in Rochet and Tirole (2002). Other types of competition are considered in Wright (2003) while competition between payment networks are discussed by Guthrie and Wright (2007) and Chakravorti and Roson (2006). In the model, the assumption about competition results in a threshold: Those merchants whose benefit exceed the threshold accept cards, and others do not. However, under certain assumptions the same threshold can be shown to hold under other types of competition, including perfect competition (Rochet and Tirole, 2011). Further references to the literature on interchange fees can be found in the surveys by Chakravorti (2003) and Verdier (2011). Börestam and Schmiedel (2011) provides a good overview of the institutional details in the market for payments cards.

The rest of the paper is organized as follows. The baseline model is presented in Section 1.2. Results are in Section 1.3. A numerical illustration of the model is presented in Section 1.4. Section 1.5 concludes. Proofs are in the appendix.

1.2. Model

The model features three types of agents: consumers, merchants, and banks. Consumers have a unit demand for a good which is sold by merchants, and consumers choose which merchant to buy from depending on prices and their card acceptance policies. Banks set merchant fees collectively. Merchant fees are the same as interchange fees in the model. Consumers and merchants also respectively decide whether to use payment cards and accept card payments.

Merchants

Merchants are organized in pairs. For each merchant pair, the two merchants (or sellers, "S", following the notation in the reference literature) enjoy identical benefits b_S from accepting cards. These benefits can be interpreted as the cost savings of receiving payment by card rather than cash. The two merchants are located at opposite ends of a line segment ("linear city") of unit length and compete for consumers who are uniformly distributed across the segment. Merchants produce a good which costs γ to produce and set prices p_i $(i = 1, 2)$ to maximize profits. In addition, merchants choose whether to accept card payments. If they accept payment by card, they must pay a merchant fee of m when consumers use cards. Merchants may also face a fixed cost K if they choose to accept cards; in the results section, I discuss both the cases with and without such fixed costs. Merchants are heterogeneous across pairs, with benefits distributed according to a cumulative distribution function $G(b_S)$ with full support on the interval $[b_{S,min}, b_{S,max}]$. I initially assume that merchants are prohibited from surcharging, but relax this assumption in an extension to the model.

Consumers

For each merchant pair there is a unit mass of consumers (or buyers, "B"). Each consumer is randomly matched with a merchant pair and demands a single good. A consumer is described by a location $x \in [0, 1]$ in the unit interval between the two merchants. The consumer must pay a distance cost xt if purchasing from merchant 1 or a distance cost $(1 - x)t$ if purchasing from merchant 2.

Consumers are heterogeneous in the benefits they derive from paying by card. The assumption is that all consumers have a payment card and do not face any adoption costs. In the first part of the results section, however, I address the question of existence of equilibria in the more general case where consumer adoption costs are present. The consumer benefits are denoted b_B and are distributed according to cumulative distribution function $H(b_B)$ with full support on the interval $[b_{B,min}, b_{B,max}]$. One can interpret the consumer benefit as consumers' willingness-to-pay for being able to pay by card rather than cash. When choosing which merchant to frequent, a consumer who enjoys benefits b_B compares the total cost of purchasing the good at each merchant. For example, if merchant 1 accepts cards and merchant 2 does not, a consumer who prefers card to cash payment (i.e. $b_B > 0$), shop at merchant 1 when: $p_1 + xt - b_B \leq p_2 + (1 - x)t$.

The cumulative distribution functions of the consumer and the merchant are assumed to be twice continuously differentiable. To illustrate results in a simple setting, I occasionally consider the case where merchant and consumer benefits are uniformly distributed to facilitate a simple interpretation of the results. A sufficient condition for guaranteeing concavity of the optimization problems faced by agents is that the hazard rate $\frac{g(b_S)}{1-G(b_S)}$ be increasing, a property satisfied by many widely-used distributions (e.g. uniform, normal, logistic, etc.).[6]

Banks and welfare

Banks produce payment services and set merchant fees m collectively in order to maximize joint profits. No distinction is made between consumers' and merchants' banks. This can be motivated by an assumption of perfectly competitive merchant banks. In that case the merchant fee can be written as the sum of the interchange fee and the merchant banks' marginal cost of producing card payments: Distinguishing between consumer and merchant banks is thus of no economic consequence. To keep notation simple, I will therefore treat consumers' and merchants' banks as one with the implicit understanding that there is a one-to-one relationship between the interchange fee and the merchant fee - the merchant fee equals the interchange fee plus a constant (the merchant bank's cost) which I normalize to zero. Banks face variable costs of c_C which are proportional to the fraction of card payments in the economy. Banks obtain card revenue from merchants, and this revenue is equal to the product of the merchant fee m and the fraction of card payments in the economy. In addition, banks face costs related to the production of cash payment services, denoted c_D, and these are proportional to the fraction of cash payments in the economy.[7]

The banks' joint objective is then to maximize:

$$\Pi = (1 - H(b_B^\star))(1 - G(b_S^\star))(m - c_C) - (1 - (1 - H(b_B^\star))(1 - G(b_S^\star)))c_D \tag{1.1}$$

where $b_B^\star$ and $b_S^\star$ denote the thresholds above which consumers and merchants use and accept cards. The first part of the expression is the profits due to card payments, and the last part is the cost associated with cash payment services. For much of the paper the assumption is that $b_B^\star = 0$, as consumers do not pay for the use of payment instruments, though this assumption must be altered when consumers are subject to surcharging. Note also that $b_S^\star$ is a function of the merchant fee, but that this dependence has been suppressed to simplify notation. I denote to the total fraction of card payments as:

$$\mu(m) \equiv (1 - H(b_B^\star))(1 - G(b_S^\star)) \tag{1.2}$$

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[6] Such a condition is generally applied in the reference literature. In fact, this condition is sometimes more than sufficient as a weaker condition could be imposed.

[7] In the model I assume for simplicity that the social costs of producing payments, c_C and c_D, are the same as banks' private costs. More realistically, banks may have some cost recovery from consumers. In the numerical analysis of the model I discuss the difference in private and social cost.

The presence of cash is taken for granted, that is, banks cannot choose not to provide cash payment services. The rationality constraint facing banks is therefore that they must be no worse off providing card payment service than they would be in a pure cash economy, i.e.:

$$\mu(m)(m - c_C) - c_D(1 - \mu(m)) \geq -c_D \tag{1.3}$$

The social planner maximizes the total benefits resulting from the use of payment cards less the costs associated with the production of payments. The social planner's objective function is:

$$\begin{aligned} W = (1 - G(b_S^\star)) \int\limits_{b_B^\star}^{b_{B,max}} b_B dH(b_B) + (1 - H(b_B^\star)) \int\limits_{b_S^\star}^{b_{S,max}} b_S dG(b_S) \\ -\mu(m)c_C - (1 - \mu(m))c_D - (1 - G(b_S^\star))K \end{aligned} \tag{1.4}$$

In derivations I assume that $b_{B,min} < 0 < b_{B,max}$ and that $b_{S,min} < b_S^\star < b_{S,max}$ in order to avoid having to deal with "corner solutions" in which either all merchants or consumers use cards.[8]

1.3. Results

I first examine the question of card adoption in the economy. In particular, when is an equilibrium guaranteed to exist in the most general case where both consumers and merchants face adoption costs? This represent a departure from the assumption made in the baseline model described above and in much of the related literature where neither merchants nor consumers face adoption costs.[9] The introduction of consumer adoption costs adds extra generality - it makes the market truly two-sided in the sense that consumers' adoption decision will then depend on the fraction of merchants accepting cards, while merchants' acceptance decision depends on the fraction of consumers with cards - but comes at the expense of weaker results. It turns out that one can specify the conditions under which an equilibrium exists, but a unique equilibrium cannot be guaranteed. For the remainder of the analysis I therefore dispense with the assumption that consumers face adoption costs. This simplification can be justified if consumer adoption costs are negligible in practice as, for most individuals, they seem to be: It is common for consumers to automatically be provided with a payment card as part of the basic banking services to which they have access, and so the critical decision is the usage decision, which depends on the marginal cost of paying with different payment instruments, and not the adoption decision.[10]

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[8] This issue will be taken into account when I examine the model numerically; in that case, it will become apparent that the last assumption is not satisfied for low values of m at which all merchants accept cards.

[9] A notable exception is McAndrews and Wang (2012), who employ a model of quite different style than is the standard in the literature.

When consumers face fixed adoption costs, which I denote k, their decision to get a card will depend not only on the price of paying by card, which is zero by assumption, but also on the fraction of merchants accepting cards. Merchants' decision, in turn, depends on the fraction on consumers using cards; this is the case independently of whether merchants face a fixed adoption cost. The effect of introducing consumer adoption costs is to make the market truly two-sided in the sense that each side of the market, consumer and merchant, makes a participation choice which depends directly on the participation choice of the other side.

To show the existence of equilibria it is necessary to analyze the participation choices of merchants and consumers. In the case of consumers this is straightforward. If one thinks of the consumer as choosing whether to have a payment card prior to being matched with the merchant, a consumer will adopt a payment card whenever the expected benefits exceed the adoption cost:

$$b_B(1 - G(b_S^\star)) \geq k \tag{1.5}$$

I let $b_B^\star$ denote the adoption threshold for consumers, with $b_B^\star = \frac{k}{1-G(b_S^\star)}$. Here $b_S^\star$ denotes the threshold above which merchants accept cards. For merchants the problem is slightly more involved. Merchants' acceptance threshold is given in the following lemma.

Lemma 1. *A pair of merchants accepts payment by card when the following condition is satisfied:*

$$b_S \geq b_S^\star = m - E[b_B | b_B \geq b_B^\star] + \frac{3t\left(1 - \sqrt{1 - \frac{2K}{t}}\right)}{1 - H(b_B^\star)} \tag{1.6}$$

This condition has several implications. If there are no fixed costs, i.e. $K = 0$, the condition reduces to

$$b_S \geq m - E[b_B | b_B \geq b_B^\star] \tag{1.7}$$

This is the same card adoption condition as in Rochet and Tirole (2002); and while the derivation in the appendix relies on the linear city model of competition among merchants, exactly the same condition can under in some circumstances be shown to hold under perfect competition or local monopoly (Rochet and Tirole, 2011). The condition implies that merchants might accept cards even if it increases their costs. If there is no fixed cost, though, the result has a somewhat counterintuitive implication: As the card adoption threshold for consumers increases, and fewer consumers use cards, more merchants will accept cards. This conclusion no longer follows automatically with a fixed cost, since the cost must be spread among fewer card users. While $E[b_B \mid b_B \geq b_B^\star]$ is increasing in $b_B^\star$, $1 - H(b_B^\star)$ is decreasing with opposite effect on card acceptance. Differentiation of the expression with respect to t shows the expression to be declining in t, meaning that more merchants will accept cards. In fact, the acceptance threshold is only defined for $K \leq 1/(2t)$. This makes sense since for any higher K, merchant profits would be negative if merchants accepted cards.

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[10] The discussion about the issue of "financial inclusion" shows that this assumption may not be satisfied for the most disadvantaged individuals in society who sometimes have difficulties getting access to basic banking services.

An equilibrium requires that the fractions of consumers and merchants desiring to adopt and accept cards must agree with each other as the fraction of consumers adopting cards depend on the fraction of merchants accepting cards and vice versa. In equilibrium, if a certain fraction of consumers find it optimal to adopt cards given the fraction of merchants accepting cards, it must be the case that exactly that fraction of merchants do, in fact, accept cards given the choice of the consumers. This can be formulated as a fixed-point problem, here viewed from the perspective of the merchants. There is a trivial fixed point, namely that in which cards are neither adopted by consumers nor accepted by merchants. In looking for non-trivial fixed points, I focus on benefit intervals of the form $S = [b_{S,min}, b_{S,max} - \epsilon]$, where $\epsilon > 0$. One can then formulate the problem as one of finding a fixed point of the function:

$$f(b_S) = m - E\left[b_B \mid b_B \geq \frac{k}{1 - G(b_S)}\right] + \frac{3t\left(1 - \sqrt{1 - \frac{2K}{t}}\right)}{1 - H\left(\frac{k}{1-G(b_S)}\right)} \tag{1.8}$$

Proposition 1. *The existence of an equilibrium with card adoption can be formulated as a fixed point problem. A non-trivial fixed point is represent if there exists some ϵ such that the following condition is satisfied for all b_S in S:*

$$b_{S,min} \leq m - E\left[b_B \mid b_B \geq \frac{k}{1 - G(b_S)}\right] + \frac{3t\left(1 - \sqrt{1 - \frac{2K}{t}}\right)}{1 - H\left(\frac{k}{1-G(b_S)}\right)} \leq b_{S,max} - \epsilon \tag{1.9}$$

An equilibrium is also guaranteed to exist if $f(b_{S,min}) < b_{S,min}$.

The first part of the above proposition provides a sufficient condition, guaranteeing the existence of an equilibrium. A proof is in the appendix. The case of $f(b_{S,min}) < b_{S,min}$ corresponds to an equilibrium in which all merchants accept cards, and consumers for whom $b_B \geq k$ use cards.

The expression for $f(b_S)$ highlights that two economic effects are present as b_S is varied. If b_S decreases, i.e. more merchants are willing to accept cards, more consumers will also be induced to get a card. The first effect is then that the average consumer who prefers cards to cash has a weaker preference for cards than before since the marginal card users are those with a weak preference for cards. This means that fewer merchants will want to accept cards. The second effect is that as more consumers wish to pay by cards, merchants can spread their fixed cost across more consumers, making them more likely to accept cards. These offsetting effects suggest that there might be two equilibria, one in which cards are widely used and one in which they are less widely used. When I analyze the model quantitatively based on cost of payments data, I show that two equilibria do indeed result for various values of m; however, if one were to think of the model in dynamic terms, only the high card usage equilibrium would be a stable equilibrium.

It is also possible to say something about the effect of changing other parameter values. An increase in k, for instance, has the immediate effect of reducing the fraction of consumers using cards. Following the same logic as before this has two effects: Only those consumers with the strongest preferences cards remain, making it more attractive for merchants to accept cards, but the fixed cost element increases. Indeed, there is a limit to how high k can become as the fixed cost term will tend to infinity as k increases and b_B approaches $b_{B,max}$. For the same reason, ϵ cannot be chosen arbitrarily small since $f(b_S)$ tends to infinity for b_S too close to $b_{S,max}$. In plain terms, if cards are to adopted it must not be too expensive for consumers to obtain a card. It is likewise clear that merchant fixed costs cannot be too high. Finally, equilibria are more likely to be guaranteed to exist when the maximum benefits enjoyed by consumers or merchants are high.

For the remainder of the analysis it is assumed that consumer adoption costs (k) are zero. The above was intended to highlight the economic mechanisms which are at work in the general case. Stronger and much more interesting results obtain when entertaining the assumption of no consumer adoption costs. As noted earlier, this assumption does not seem too unreasonable as a payment card is often automatically provided as part of a package of basic banking services. When $k = 0$ there is a unique equilibrium with a number of noteworthy properties and policy implications.

Turning to the baseline model without consumer adoption costs, it is possible make an unambiguous statement about the effect of interchange fees on card usage, as detailed in the following proposition.

Proposition 2 (Card usage and interchange fees)**.** *When consumers do not face adoption costs, i.e.* $k = 0$*, card usage is declining in interchange fees.*

The intuition underlying this result is straightforward. When consumers' marginal cost of paying is zero, the interchange fee does not affect their incentive to pay by card. Those who prefer to pay by card will do so when they can, independent of the interchange fee. On the other hand, fewer merchants accept cards, and so a number of individuals who would have liked to pay by card are no longer able to. The result is fewer card payments. This contrasts with the results of Rochet and Tirole (2002) who find that excessive interchange fees are associated with *too many* card payments.

This establishes that card usage is decreasing in merchant fees or, equivalently, in interchange fees, thus providing a possible explanation of why countries without interchange fees also exhibit a high fraction of card payments. While the result does not have a direct bearing on the issue of whether privately set interchange fees are optimal, it does show that if privately set interchange fees exceed the social optimum, then the resulting outcome will be too few card payments.

As an empirical matter, it is difficult to verify a link between interchange fees and card usage for at least two reasons. The first is absence of data; frequently, interchange fee levels are not publicly disclosed. The second reason is that the observed interchange fees are endogenous. In a number of countries, however, fee levels have been imposed by regulation. This has often been the case in countries where national card schemes have been in existence, such as in the European countries discussed in the introduction. Empirical evidence on the link between interchange fees and card usage, while scarce, is consistent with the model's predictions. As described in the introduction, Börestam and Schmiedel (2011) report that in 2006, four European countries had national card schemes, which operated without interchange fees, namely Denmark, Finland, Luxembourg and the Netherlands. These were also among the countries with the most card payments. Other countries with relatively many card payments were France and Portugal. Börestam and Schmiedel (2011) also mention that interchange fees are regulated in France, and report fairly low interchange fee levels in Portugal compared to these in neighboring Spain where card payments are much rarer.[11] These findings are by no means conclusive, but they certainly are suggestive.

A natural follow-up question is whether interchange fees as set by banks are biased relative to the social optimum? The answer is yes: Privately set fees exceed those set by the social planner, except in special cases. In order to arrive this conclusion, it is necessary to compare the optimal choices for the banks and the social planner. This is the content of the next lemma and proposition.

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[11] Data on card usage across countries can be found in chart 3 in the cited paper while interchange fee levels for Spain and Portugal are reported in charts 6 and 7.

Lemma 2. *Banks' profit-maximizing merchant fee is indirectly defined by:*

$$m = c_C - c_D + \frac{1 - G\left(m - E[b_B \mid b_B \geq 0] + \frac{3t\left(1-\sqrt{1-\frac{2K}{t}}\right)}{1-H(0)}\right)}{g\left(m - E[b_B \mid b_B \geq 0] + \frac{3t\left(1-\sqrt{1-\frac{2K}{t}}\right)}{1-H(0)}\right)} \tag{1.10}$$

The expression from banks' equating marginal revenue and costs. It is the price formula of a monopolist, and $\frac{g}{1-G}$, the absolute mark-up, can be thought of as reflecting merchants' demand elasticity, with a high value representing a low demand elasticity and high market power.

An interesting, testable implication relates to the connection between the degree of merchant profitability and the fees paid by merchants to banks. In the linear city model, profitability is a linear function of the transport cost, t, which can e.g. be interpreted as the degree of competition or product differentiation. As summarized in the following corollary, one can show that merchant fees will be higher when t is higher. In other words, banks will charge higher fees from merchant which themselves are more profitable.

Corollary 1. *The more profitable merchants are (the higher t), the higher merchant fees banks charge.*

To help build further intuition about the profit-maximizing fee, it is interesting to consider how the expression looks under specific distribution assumptions. With uniformly distributed benefits, the expected benefits of card users are:

$$E[b_B | b_B \geq 0] = \frac{1}{2} b_{B,max} \tag{1.11}$$

Ignoring merchant fixed costs, this means that the optimal privately set merchant fee can be shown to be:

$$m = \frac{1}{2}\left(c_C - c_D + b_{S,max} + \frac{1}{2} b_{B,max}\right) \tag{1.12}$$

This tells us that banks will increase fees both when consumer and merchant preferences for cards strengthen.

As will be shown in the following, neither terms involving consumer nor merchants benefits appear in the expression for the socially optimal fee. This is because banks are effectively acting as monopolists. If consumer prices for payment services are fixed, the market becomes one-sided as an increase in merchant fees is not counterbalanced by a reduction in consumer marginal costs. Banks set a fee that exceeds their marginal cost, resulting in too few card payments. The expression furthermore indicates that merchant fees are more responsive to changes in merchant benefits than to changes in consumer benefits. It also shows that merchant or interchange fees should be falling as the costs of producing card payments decline. However, privately set fees increase if consumers' or merchants preferences' change in favor of card payments. Such an argument could perhaps explain why merchant fees have not declined over time in the US in spite of falling technology costs (McAndrews and Wang, 2012).

Banks' optimal merchant fee can be compared to the corresponding first-order condition for the social planner, again ignoring merchant fixed costs.

Proposition 3 (Socially optimal interchange fee)**.** *When merchant fixed costs are zero, the socially optimal interchange equals the difference in banks' marginal cost of producing card and cash payments, i.e.*

$$m = c_C - c_D \tag{1.13}$$

The expression for socially optimal merchant fee is remarkably simple, and the optimal fee can be determined solely based on costs. At first glance, the optimization problem facing the social planner seems rather complicated and more so than that facing the banks, yet the resulting expressions are relatively similar, except for a mark-up term. Intuitively, what the social planner is attempting to do is to put cards and cash on an equal footing by setting merchant fees to reflect the difference in marginal cost between the two. To the extent that card payments are cheaper to produce than cash payments, merchants should be induced to accept cards via negative fees. This is essentially the same as the standard socially optimal pricing strategy of setting price equal to marginal cost, except that now both the cost of card and cash payments must be considered. Comparing the planner's problem with the banks also points to the sources of bias in banks' fee. A key source is that the total consumer benefits depend on the fraction of merchants accepting cards, and this loss to consumers from too few merchants accepting cards is not internalized by banks.

It is straightforward to verify that the banks' rationality constraint is satisfied with equality at the socially optimal fee. An immediate consequence of the preceding results is therefore that the profit-maximizing merchant fee always exceeds or equals (for equality, see the later discussion of the special case of homogeneous merchants) the welfare-maximizing fee.

Proposition 4 (Profit-maximizing versus socially optimal interchange fees)**.** *Banks always set interchange fees that exceed or equal those preferred by a social planner.*

A corollary, which is interesting from a regulatory perspective, is that the model suggests a different path for interchange fees than does the merchant indifference test, which is favored by some regulators. As pointed out by Bolt et al. (2013), the merchant indifference test methodology would logically lead to increasing interchange fees over time as the technological evolution would presumably lead to lower card costs (c_C) whereas the cash handling costs (c_D) might not decrease correspondingly as cash handling is more labor-intensive and thus becomes more expensive as wages rise. In contrast, the model tells us that (optimal) interchange fees should fall over time as c_C decreases or c_D increases. A direct comparison between the level of the optimal interchange fee and the fee implied by the merchant indifference test is not possible for the simple reason that merchants are heterogeneous; exactly which merchant is supposed to be indifferent?

In the preceding it was assumed that there were no merchant fixed costs, i.e. $K = 0$, but an identical logic applies in the case of positive fixed costs for merchants. The formula for privately optimal interchange fee is unchanged, though the fee itself will change due to the effect of K on the merchant acceptance threshold. The formula changes, however, in the case for the socially optimal fee. It can be shown to be:

$$m = c_C - c_D + \frac{K - 3t\left(1 - \sqrt{1 - \frac{2K}{t}}\right)}{1 - H(0)} \tag{1.14}$$

The resulting expression is no longer purely cost-based as $1 - H(0)$ depends on the distribution of consumer benefits. That in itself does not pose too rigorous an informational requirement for a social planner since $1 - H(0)$ is just the fraction of card users in the economy, which is likely to be observable. It is rather the presence of a variable such as the distance cost, t, which makes the expression impractical. Aside from added simplicity, at least four arguments can be made for ignoring the fixed cost term, and using $m = c_C - c_D$ as the benchmark when evaluating merchant fees. First, K might be small in practice and therefore of little consequence. Second, including the fixed cost term implies an even lower socially optimal merchant fee. Third, at $m = c_C - c_D$ it might be the case that the merchant threshold is actually lower than $b_{S,min}$, in which case a further reduction in fees is of no consequence. Fourth, the first part of the expression merchant acceptance threshold, i.e. $m - E[b_B \mid b_B \geq 0]$, also holds under alternative assumptions about merchant competition (such as perfect competition), whereas the fixed cost component depends on the degree of competition which may differs across industries and would therefore suggest a need for differentiated optimal fees.

To see that the inclusion of merchant fixed cost produces a lower socially optimal merchant fee, one needs to determine the sign of $K - 3t\left(1 - \sqrt{1 - \frac{2K}{t}}\right)$. This expression must be negative since

$$K - 3t\left(1 - \sqrt{1 - \frac{2K}{t}}\right) \leq 0 \Leftrightarrow 3t\sqrt{1 - \frac{2K}{t}} \leq 3t - K \tag{1.15}$$

Both sides of the last expression must be positive if cards are accepted by merchants. In an equilibrium where merchants accept cards, it must be the case that $\frac{1}{2}t \geq K$, since otherwise merchants would be making negative profits. That means that $3t - K > 0$. Squaring both sides and simplifying the expression, results in the expression $-12t \leq K$ which is obviously true.

There is a special circumstance in which the privately set interchange fee is also socially optimal, namely when merchants are homogeneous, that is, they enjoy the same b_S across all merchant pairs.

Proposition 5. *When merchants are homogeneous, i.e. enjoy the same b_S across all merchant pairs, there is an interval of socially optimal interchange fees. Banks' choose the highest among these.*

An interpretation is that to the extent that merchants are relatively homogeneous, the exact level of the interchange fee may not matter too much from a welfare perspective, as long as it is within certain bounds. In that case the consequences of changing the interchange fee level are mainly distributional, and the real question is whether banks or merchants reap the benefits.

The preceding results may also shed light on the public debate about interchange fee regulation. Banks have been highly critical of such regulation whereas especially merchants, but also consumer organizations, have been favorable to it.[12] This is perfectly consistent with the model since caps on interchange fees would benefit consumers and merchants, but eliminate bank profits. If the more traditional view of the functioning of interchange fees were true, it is hard to rationalize why consumer representatives would support such regulation (and potentially also hard to see why banks would oppose it so strongly if interchange fee revenue were passed on to consumers).

Finally, why exactly is it that these results differ from those in the reference literature? In that literature, consumers' banks are assumed to charge transaction fee equaling their cost of producing payment services, perhaps with markups to reflect imperfect competition. Higher interchange fees therefore translate into lower consumer transaction fees and a greater willingness to use cards among consumers. If merchants are homogeneous (Rochet and Tirole, 2002), the effect is that card usage is increasing in interchange fees, at least up to a point where merchants refuse to accept cards. If merchant heterogeneity is taken into account (Wright, 2004), fewer merchants accept cards as interchange fees increase, and there will no longer be a monotone relationship between interchange fees and card usage. When consumers do not pay transaction fees, the first of these mechanisms breaks down: Lower fees no longer induce consumers to pay by card instead of using cash. The only effect is to limit merchant acceptance which implies that card usage decreases in interchange fees.

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[12] For a flavor of the debate in Europe one can look at the responses by different groups to the public consultations held by the European Commission.

The unconventional results of the model emerge because banks' pricing structure makes the market essentially one-sided. Banks then effectively act as monopolists towards merchants and set interchange fees in excess of the social optimum, which equals the difference in marginal costs between card and cash payments. A corollary is that the optimal fee is likely to be close to zero, unless one believes that the marginal cost of paying by card or cash is very high relative to the other. To rationalize a high positive fee, one would have to argue that card costs are high relative to cash costs. Also, while the existence of a cost-based optimal fee hinges on a number of model assumptions, it remains a useful benchmark when those are violated. For instance, when merchants pay fixed costs to be able to receive card payments, the optimal fee is no longer purely cost-based, but the cost-based fee then provides an upper bound for the optimal fee.

The special case of homogeneous merchants is of some interest. If all merchants enjoy the same cost-savings from card payments, the effects of interchange fee regulation are then purely distributional, a matter of whether merchants or banks pay for payments. In fact, much of the debate on the effects of interchange regulation is couched in terms of the distributional consequences (Wang, 2012).[13]

I next consider some extensions to the model, but first discuss why zero transaction fees are so common. Then I examine the consequences of permitting merchants to surcharge merchant fees. I also consider a variant of the model where banks must pay a fixed cost to operate the card payment system. Related to this, I discuss the incentives for banks to invest in innovations that either enhance benefits for consumers and merchants or reduce costs.

1.3.1. Pricing card payments

The key assumption of this paper is that transaction fees are zero. While this is an empirical regulatory, it clearly is not always the case. There are plenty of counterexamples in the form fees which are effectively negative (either directly in the form of cashbacks or indirectly in the form of other "benefits" such as loyalty bonuses). On the other hand, strictly positive fees are rare. Tirole (2015) attributes low and perhaps negative consumer fees in two-sided markets to consumers having highly elastic demand, though that does not quite explain why a fee of exactly zero is so commonly observed, especially for debit cards.[14] It is difficult to write down a model which produces a fee of exactly zero.

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[13] The European cost of payment studies also provide an illustration that this may be the case. Comparing Denmark and Sweden is a case in point. These countries show roughly the same outcomes in terms of the proportion of cash and card usage, and while there is no interchange fee in Denmark, interchange fees (low by international standards) are applied in Sweden. A key difference between these countries is that Swedish banks have much more profitable payment operations than do Danish banks.

One possible explanation of this phenomenon is cross-subsidization. Banks appear to set prices differently depending on the type of banking product, with some products being bargains and others "rip-offs" (Heffernan, 2002). Indeed, many of the national cost of payment studies - on which the European Central Bank study (Schmiedel et al., 2012) is based - show that banks not only do not charge transaction fees, but frequently fail to even cover their costs when providing payment services. One possible explanation of this is that banks use free payment services as a means to attract retail consumers who provide inexpensive funding in the form of the deposits. The Danish cost study (Danmarks Nationalbank, 2011), for example, shows that banks fail to recover their costs for practically all of the payment services they provide. However, the authors of the study also point out that banks' deficit all but vanishes when taking into account the low interest rates paid on current account balances. The Economist puts it succinctly: "To consumers, most payments appear to be free because they are given away by banks as part of a bundle of banking services that some customers subsidise through low interest rates on deposits."[15]

Behavioral factors may also help explain the predominance of "zero". People, it seems, dislike paying for payments. One reason might be that when payment cards were introduced, they typically did not feature any transaction fees so as to make them competitive with the readily available alternative in the form of cash, whose use did not entail a direct monetary cost. The behavioral literature suggests that people can have a strong aversion to paying for something which used to be free: This is experienced as a loss and is costly to loss-averse individuals.[16] When interchange fee regulation was introduced in the US, some banks began charging fees, but soon reversed course due to strong consumer reactions.[17] It could also reflect a social norm against "paying for payments". One also does pay when going for dinner at a friend's place: It is not that this experience is not valuable, but simply that being asked to pay would violate a norm.

Even though the reasons for this phenomenon are not entirely understood, therefore, it seems reasonable to consider models in which banks do not charge positive fees. To consider more formally the fee decision facing banks, suppose then that individual banks sets a fee (f), which we restrict to be non-positive. Suppose further that any individual bank takes as given the interchange (merchant) fee (m) and the fraction of merchants accepting card ($1 - G(b_S^\star)$). Finally, assume that a bank faces some net costs (c) when consumers make card payments[18], reflecting the difference in costs relating to dealing with card and cash payments respectively, that are proportional to the use of cards by the bank's customers.

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[14] This is certainly the case in many European countries. A cursory glance at their websites of large European retail banks show that these typically offer a choice of relatively few cards to consumers. There seems to be more variety in the US. Klein et al. (2006) report that J.P. Morgan Chase, a large issuer of Visa cards, was offering no less than 57 co-branded cards (and 122 affinity cards) on its website in 2005.

[15] The Economist, 19 May 2012.

[16] A curious tale of this phenomenon is provided in the radio episode "The Cost of Free Doughnuts: 70 Years of Regret", available at NPR, which explains why US soldiers to this day hold a grudge against the Red Cross, because the Red Cross started charging them for doughnuts in 1942!

[17] See, for example, the articles "BofA Retreats on Debit Fee, Citing Uproar" and "Retreat From Debit-Card Fees Continues" in the Wall Street Journal, both from 1 November 2011.

If the bank is perfectly competitive, it will set a fee of $f = c - m$. If interchange fees are positive and card payments no more expensive than cash payments to produce (at least, no more than the size of the interchange fee), one should expect consumers to pay negative fees, i.e. receive cash-backs when paying by card. It follows that a binding constraint in the form of zero transaction fees are unlikely to be observed when banks are perfectly competitive.

At the other extreme, consider the case in which banks have monopoly power towards their consumers. In that case banks maximize:

$$(f + m - c)(1 - G(b_S^\star))(1 - H(f)) \tag{1.16}$$

Now, if we assume that each bank is small, a change in f by any individual bank will not affect $b_S^\star$. In that case the resulting optimal fee is implicitly defined by the following equation:

$$f = c - m + \frac{1 - H(f)}{h(f)} \tag{1.17}$$

This implies that banks will charge higher fees when the elasticity of demand is low. Inserting the expression for the optimal merchant fee (here I write it simply as a function of m, but it also depends on other parameters), we find:

$$f = -\frac{1 - G(m)}{g(m)} + \frac{1 - H(f)}{h(f)} \tag{1.18}$$

Hence, the non-positivity constraint binds if:

$$\frac{1 - H(f)}{h(f)} \geq \frac{1 - G(m)}{g(m)} \tag{1.19}$$

The expressions on either side reflect the absolute mark-ups in the consumer and merchant market respectively. One can therefore think of them as representing measures of market power.

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[18] For simplicity, I assume that $c = c_C - c_D$, i.e. that the individual bank's net costs are identical to those of the banking sector more broadly; it is straightforward to generalize to the case where the individual card issuing bank's costs differ from the aggregate costs.

One can explicitly express the above as a function of preferences and costs under the assumption of uniformly distributed benefits. In that case the optimal consumer fee is $f = \frac{1}{2}(c - m + b_{B,max})$. Inserting the expression for the optimal m under the assumption of zero transaction fees, one can show the non-positivity constraint to bind when:

$$\frac{3}{2} b_{B,max} - b_{S,max} + c \geq 0 \tag{1.20}$$

This suggests that zero transaction fees are an equilibrium outcome when consumers have a strong preference for cards relative to merchants. Intuitively, if consumers have strong preferences for card payments, they do not need to be "bribed" with e.g. cash-backs to use cards.[19] As for merchants, the optimal transaction fee does not directly depend on merchant preferences. However, it does so directly through the interchange fee. If merchants have strong preferences for cards, the optimal interchange fee is higher, and the lower the optimal interchange fee, the lower the optimal transaction fee.

As an intermediate case where we are able to vary the degree of market power parametrically, we can consider applying a linear city model of competition to banks (competing for consumers by setting card fees). In that case the optimal fee is:

$$f = c - m + t \tag{1.21}$$

The optimal merchant fee, as before, is $m = c + \frac{1-G}{g}$, with $\frac{1-G}{g}$ reflecting merchants' demand elasticity for card payments at the optimal fee. An equilibrium with a binding constraint, i.e. transaction fees set at zero, then results if:

$$t > \frac{1-G}{g} \tag{1.22}$$

One can think of this as characterizing a relationship between market power in the consumer and merchant markets respectively. Under that interpretation, we can then summarize the above findings as follows:

Proposition 6. *Zero transaction fees can emerge as an equilibrium outcome when banks have strong market power in the market for consumers and weak market power in the market for merchants.*

The above discussion only scratches the surface of how payment cards are priced, and other considerations, for example the apparent tendency of banks to price some financial services cheaply (for example, payment services) while making money on others (for example, earning high spreads due to low deposit rates), seem likely to be important factors. Some of the salient features of typical bank contracts indicate that such cross-subsidization takes place. For instance, bank contracts typically specify that payment services are only free provided that customers provided that certain conditions are met, for instance that consumers maintain their salary accounts with the bank, or that customers have a certain volume of business with the bank. An exception from such requirements is typically made for younger customers, likely reflecting asymmetric information about the value of such consumers to the banks.[20]

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[19] Note that this could be also help explain why card payments are especially prevalent in countries with low interchange fees: A preference for card payments may explain both high card usage and low interchange fees.

1.3.2. Surcharging

Where permitted and applied, surcharging has the potential to neutralize the effect of interchange fees. Two questions arise in the context of surcharging. First, will merchants surcharge if permitted? Second, what are the welfare consequences of surcharging? Both questions, it turns out, defy simple analytical answers, but the analysis (including the subsequent numerical illustration) nevertheless provides valuable insights into the effects of surcharging.

In practice, surcharging can be applied in more ways. In Europe, for example, companies such as airlines have been criticized for surcharging amounts in excess of their merchant fees. In the following I look at the case where merchants are permitted to surcharge only the amount of the merchant fee or not surcharge at all. Such a requirement is typically stipulated in regulations of surcharging.

Admitting the possibility of surcharging complicates the strategic options for merchants. Where before they faced a choice between accepting cards (and not surcharging) and not accepting cards, the presence of surcharging introduces a third option which is to accept cards and surcharge the amount of the merchant fee. To check whether or when a surcharging equilibrium exists, it is therefore necessary to compare merchant profits when both merchants surcharge with their profits when deviating by either not accepting cards or accepting cards and not surcharging. As in the no-surcharging case, this problem can be tackled by finding the values for b_S for which deviating to either not accepting cards at all or accepting cards and not surcharging is not profitable.

It can be shown that when both merchants accept cards and surcharge, each merchant earns profits of $\pi = \frac{1}{2}t - K$. This is the same as when both merchants accept cards and do no surcharge, and a proof proceeds along the same lines as in the no-surcharging case. The next lemma identifies the values of b_S for which deviating by not accepting cards is not profitable.

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[20] As a more general point, it could be the case that banks do not charge transaction fees because consumers for some reason prefer flat fee contracts. DellaVigna and Malmendier (2006) contains an interesting discussion of the possible reason why flat-fee contracts are so commonplace. Their application is gym membership - why people pay not to go to the gym - so some of the possible arguments may not be too relevant in a financial services context.

Lemma 3. *If both merchants accept cards and surcharge, neither merchant is better off not accepting cards provided that:*

$$b_S \geq m - E[b_B | b_B \geq m] + \frac{3t\left(1 - \sqrt{1 - \frac{2K}{t}}\right)}{1 - G(m)} \tag{1.23}$$

The acceptance threshold is nearly identical to that in the no-surcharging case, even though the problem facing merchants is different in the two cases. There are two differences. First, $E[b_B|b_B \geq m]$ appears instead of $E[b_B|b_B \geq 0]$. Since this term is increasing in m, this tends to lower the benefit threshold above which merchants accept cards. Second, as m increases, $1 - H(m)$ decreases, and average fixed costs increase, thus reducing merchants' inclination to accept cards. It is somewhat surprising, though, that the first term survives unaltered. Intuitively, it might seem merchants should be indifferent to the level of the merchant fee, since they can choose to pass it on to consumers, but the model shows this intuition to be faulty.

Establishing the conditions under which a merchant will not want to deviate by accepting cards and not surcharging is more involved, and it does not result in a simple closed-form expression. A derivation of the no-deviation condition in this case can be found in the appendix. I examine merchant's choice problem more closely as part of the numerical analysis of the model. The numerical analysis shows that there might be multiple, even asymmetric, equilibria depending on the values of m and b_S. This makes it complicated to derive optimal merchant fees is in the same fashion as in the no surcharging case.

A simpler problem is to examine what were to happen if the only alternatives were not accepting cards or accepting cards and surcharging. In the following I abstract from merchant fixed costs in order to simplify the analysis. If merchant fixed costs were included, it would entail a negative effect on card usage, at least assuming that merchant fees are positive. That would be the case because the fixed cost element in merchants' decision problem increases as the fraction of card using consumers shifts from $1 - H(0)$ to $1 - H(m)$, contributing to making merchants less willing to accept cards. Thus, ignoring fixed costs understates any negative effects surcharging might have on card usage.

With surcharging the banks and the social planner must take into account the fact that higher merchant fees reduce consumers' willingness to use cards, a feature of the problem which was absent in the no-surcharging case. If one solves the banks' optimization problem, the optimal merchant fee is indirectly defined by:

$$m = c_C - c_D - \frac{\mu(m)}{\mu'(m)} \tag{1.24}$$

At first glance, this looks like the corresponding condition when surcharging is prohibited. However, where $\mu(m) = (1 - H(0))\,(1 - G(m - E[b_B \mid b_B \geq 0]))$ in the no-surcharging case, the corresponding expression with surcharging is (again, ignoring merchant fixed costs).

$$\mu(m) = (1 - H(m))\,(1 - G(m - E[b_B \mid b_B \geq m])) \tag{1.25}$$

This highlights some of the mechanisms at work when surcharging is applied. In that case, a higher merchant fee leads fewer consumers to use cards. As discussed above, the consequences are unclear for merchants as there are two effects of opposite sign. The higher fee has the effect of leading fewer merchants to accept cards via the direct effect of m on the acceptance threshold, but also makes it somewhat more attractive to accept cards due to the indirect effect (via $E[b_B \mid b_B \geq m]$) that the remaining card users are individuals with a very strong preference for using cards. As for solving the social planner's problem, this likewise produces a more complicated expression for the optimal merchant fee, and it is no longer a simple function of costs.

It is also interesting to consider the effect of surcharging on card usage. It turns out that, for a given merchant fee, one can express the conditions for decreased (or increased) card usage relatively simply, as detailed in the following proposition.

Proposition 7. *For a given (positive) merchant fee, fewer consumers use cards while more merchants accept cards. Surcharging reduces total card usage whenever the percentage decrease in the fraction of card users exceeds the percentage decrease in the fraction of merchants accepting cards that would occur if surcharging were prohibited.*

To the extent that consumers are more responsive to an increase in the price of using cards than are merchants to the disadvantage of not being able to surcharge, card usage will decrease. The general assumption seems to be that consumers are quite responsive to surcharging whereas merchants do not drastically alter card acceptance policies depending on whether surcharging is permitted or not. In fact, it mainly appears to be large merchants that surcharge, and they generally accept payment cards.

The above, as stated, is true with the important proviso "for a given merchant fee". It does not to take into account the behavioral changes that surcharging will have on the merchant fee which itself is endogenous. Banks are likely to charge a lower merchant fee in the first place if surcharging is permitted.

The above discussion highlights another feature of surcharging: It does not neutralize the effect of interchange fees. The ordinary logic that surcharging might neutralize interchange fees can be illustrated by considering what would happen if, say, interchange fees were increased. In that case consumers would face lower fees from their banks, but that would be offset by having to pay the surcharged fee itself. Hence, consumer behavior would not change. Also, since merchants can surcharge the additional cost, their profits would be unchanged by any change in interchange and thereby merchant fees. This leads to the conclusion that interchange fees are irrelevant when surcharging is applied.

Such a conclusion does not hold for this model. As discussed above, a higher interchange or merchant fee leads fewer consumers to use cards, and this also affects merchants' incentives to accept cards. Only by pure accident would the effects involved cancel out. This is summarized in the following proposition.

Proposition 8 (Non-neutrality of surcharging)**.** *Surcharging does not neutralize the effect of interchange fees.*

1.3.3. Fixed costs, merchant fees, and incentives for innovation

In the preceding, I assumed that the costs of processing and handling cash and card payments were proportional to the usage of cards and cash in the economy. A more realistic assumption might be that there are some fixed costs involved in operating a card payment system. This would be consistent with the evidence of decreasing average variable costs of card payments, which are documented in Schmiedel et al. (2012).

Assume now that banks must pay a fixed cost F associated with producing card payments. This alters their rationality constraint which now reads:

$$\mu(m)(m - c_C) - c_D(1 - \mu(m)) - F \geq -c_D \tag{1.26}$$

It is straightforward to verify that this constraint is no longer satisfied at the socially optimal fee. Inserting the unconstrained optimal fee into banks' objective function, it evaluates to $\Pi = -c_D - F$, which is less than the banks' profits in a pure cash economy, which are $-c_D$. Instead, the social planner must impose a constrained optimal fee, given in the following lemma.

Lemma 4. *The socially optimal merchant fee equals to difference in marginal cost between card* *and cash payments plus the average fixed cost of card payments given that merchant fee. It is:*

$$m = c_C - c_D + \frac{F}{\mu(m)} \tag{1.27}$$

The addition is that banks must be compensated to cover their average fixed costs. Note that the equation only defines the merchant fee indirectly as it appears on both sides of question. To establish the conditions under which there exists an m that satisfies the equation, one can appeal to a number of fixed point theorems in order to identify the restrictions which must be satisfied.

The banks' profit-maximizing fee does not depend on the presence of a fixed cost; I assume that banks' rationality constraint is satisfied at this fee, since otherwise there would exist no fee at which banks would be willing to produce card payments. Glancing at the expression for the privately and socially optimal fees and comparing them, it is not immediately obvious that the privately set fee must exceed that of the social planner. Some consideration shows that this must be the case. At the privately optimal fee, banks' profits exceed those earned in a pure cash economy (otherwise it would never make sense to produce card payments). The unconstrained socially optimal fee is less than the privately optimal fee, and the social objective function is decreasing for m greater than the unconstrained social optimum. That implies that fees can be reduced below the privately optimal fee and still satisfy banks' rationality constraint, whereas any fee higher than the privately optimal fee would be associated with lower welfare.

From a regulator's perspective, the expression for the constrained socially optimal fee is less satisfactory. Identifying the optimal fee imposes a greater informational demand as the optimal fee depends on knowledge of the distribution of merchant benefits (as well as the parameters t and K if merchant fixed costs are taken into account). The analysis, however, points to a superior solution from a welfare perspective, namely to impose the unconstrained optimal fee reimburse the banks the fixed costs of operating the card payment system (e.g. financed via less distorting taxes), since doing so would not involve a welfare loss from reduced card usage.[21] There is also a parallel to the case of cash where the fixed production cost is borne by the central bank.

A policy issue, which is somewhat related to the fees that banks charge or are permitted to charge, is innovation. Innovation is inherently difficult in payment schemes as multiple parties are involved in the production of a payment and must therefore adapt simultaneously. For instance, an improvement in card security might require consumers to get obtain new cards and merchants to invest in improved card terminals. The problem is exacerbated in the case of entry to the market where potential entrants confront a hen-and-the-egg problem in persuading consumers and merchants to use a payment innovation - and, in addition, may face resistance from banks who control the payment infrastructure. Setting aside such difficulties, there is the problem of financing innovation and whether banks face the correct incentives to invest.

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[21] The national debit card in Denmark is actually financed in a manner which somewhat deals with this issue. Merchants do not pay transaction fees, but rather an annual subscription that is calculated ex post, i.e. once the total number of transactions is known, and is set to cover half the costs of producing the payments.

In the context of the model, a distinction can be made between innovations that reduce costs, and those which increase benefits of either consumers of merchants. It would seem that banks should agree with a social planner on the value of reducing costs, as banks fully bear this cost. It is less obvious that this is the case for the benefits enjoyed by consumers and merchants.

This claim about costs can be verified by comparing the objective functions of banks' and the social planner. To find the value of a cost reduction, one can differentiate the respective objective functions of the banks and the social planner. Differentiation with respect to c_C affects the profit function (or social planner's objective function) directly, an effect of magnitude $-\mu(m)$, and indirectly, since the optimal merchant fee is itself a function of costs. However, the latter effect is zero by the envelope theorem. A real concern, however, is that banks' incentive to reduce transaction costs vanishes when the socially optimal fee is applied since any cost saving will also lead to lower fee income. This suggests a potential conflict between ensuring optimal fees and providing incentives for innovation.

To illustrate the point that banks might invest insufficiently in innovations that enhance benefits, consider for example a investment that would increase $b_{S,max}$. The marginal value of this increase, again applying the envelope theorem, is:

$$\frac{\partial \Pi}{\partial b_{S,max}} = g(b_{S,max})(1 - H(0))(m_{opt} - c_C + c_D) \tag{1.28}$$

If the unconstrained socially optimal fee were imposed, this would evaluate to zero. If the social planner were to ensure that the banks' individual rationality constraint remain satisfied, the social planner should allow the banks to additionally charge the average fixed cost of the cost of the innovation, in exactly the same manner as the constrained socially optimal merchant fee includes an average fixed cost component. The above expression can be contrasted with the marginal value that the social planner would assign to an increase in $b_{S,max}$:

$$\frac{\partial W}{\partial b_{S,max}} = g(b_{S,max})(1 - H(0)\left(E[b_B | b_B \geq 0] + b_{S,max} - c_C + c_D\right) \tag{1.29}$$

To give an example of the difference in incentives facing banks and the social planner, the case of uniformly distributed benefits can again be considered. We found earlier that $m_{opt} =$

$\frac{1}{2}\left(c_C - c_D + b_{S,max} + \frac{1}{2}b_{B,max}\right)$ and $E[b_B|b_B \geq 0] = \frac{1}{2}b_{B,max}$. Inserting these into the above expressions and rearranging, one sees that:

$$\frac{\partial W}{\partial b_{S,max}} = 2\frac{\partial \Pi}{\partial b_{S,max}} \tag{1.30}$$

That is, the social planner values an increase in merchant benefits twice as much as do banks. More generally, comparing the objective functions of banks' and the social planner points the sources of bias in banks' incentives. In the case of increases in merchant benefits, there are two sources of bias. As $b_{S,max}$ increases, more merchants accept cards. This benefits all of the consumers, which prefer to use cards, a positive externality which banks do not take into account in their decision making. The second source of bias is that banks' marginal revenue from the increase in card transactions is proportional to m_{opt}, whereas the corresponding value in the merchant's expression is $b_{S,max}$.

Similar considerations hold for increases in consumer benefits. The calculations are essentially the same in the case of the banks, only with the roles of the distribution functions reversed. For the social planner the problem is slightly more complicated as a third effect must also be taken into account. As $b_{B,max}$ increases, so does the average benefit to card holders $E[b_B|b_B \geq 0]$. This means that more merchants will accept cards as well. This is likely to reduce welfare, since the marginal merchant might enjoy negative benefits.

As a final note, though, regulators may not need to be too concerned about violating banks' participation constraint in practice: One finding in many of the cost of payment studies carried out in European countries is that banks are generally willing to make a loss on providing payment services, perhaps because cheap or free payment services help attract customers who purchase other profitable services from banks. In addition, as discussed in the introduction, banks increasingly seem to charge consumers fixed periodic fees and therefore do obtain income to cover costs.

1.4. Numerical Illustration

In this section I first discuss how studies on the cost of payments can be used to match the parameters of the model with data on payments. As an application, I compare the optimal interchange fee produced by the model with fees determined by alternative methods. Finally, I analyze the model when surcharging is permitted. When surcharging is introduced, it is necessary to make assumptions about the distribution of consumer and merchant benefits. I examine the case of uniformly distributed benefits.

The data used for identifying the model parameters is from a study of the cost of producing payments undertaken by the Danish central bank (Danmarks Nationalbank 2011). The study was conducted as part of a larger European Central Bank project involving 13 national central banks. A summary of the results can be found in Schmiedel et al. (2012). The Danish data are well-suited for matching the model with data for two reasons. First, the published data are detailed enough to perform a mapping of the data to the model parameters; the ECB data (Schmiedel et al., 2012), in contrast, is published at a higher level of aggregation. Second, the assumptions of the models, for example the assumption that consumers do not pay transaction fees, are satisfied in the market.

From the cost study I draw on 2009 data relating to the use and cost of producing of cash and debit card payments. The cost data have further been split into fixed and variable costs in a related analysis by Jacobsen and Pedersen (2012). I focus on the national debit card, the Dankort[22]. More than 90% of all card payments in Denmark involve this card. Its fee structure is unusual by international standards. Merchants do not pay regular merchant fees, nor is there an interchange fee. Instead, merchants pay an annual subscription fee which is set such that merchants' collective subscription payment covers half of banks' production costs. Roughly 95% of all merchants accept Dankort payments (the acceptance rate for other cards is substantially lower), and consumers generally do not pay for the use of the Dankort. Even though list prices often include an annual fee, these fees are typically waived if e.g. consumers have their current account with the bank or a certain amount of other business with the bank. Indeed, the cost study shows that banks' total Dankort income from consumers is negligible.

The intention of the analysis is to illustrate an application of the model. The actual figures will not necessarily be generalizable to other markets. As an example, Danish labor costs are high whereas card payments are produced at low cost. The result is a low, even negative optimal interchange fee. A similarly low fee is an unlikely outcome in a number of other countries where, for example, cash handling costs are lower due to lower labor costs. In fact, the ECB data suggests that cash payments are cheaper than card payments in a number of countries. Still, unless one is willing to argue that card payments are substantially more expensive to produce than cash payments - and those who favor higher interchange fees tend to make the opposite argument - the model will produce low optimal interchange fees across markets.

1.4.1. Choice of parameters

The key parameters of the model for the purpose of calculating optimal interchange fees are c_C and c_D. These reflect banks' costs as the fraction of card and cash transactions in the economy change. In the model, these figures refer to social costs, and for simplicity I assumed that banks' private costs were equal to these when, in fact, the private costs may be different as banks do obtain some income, e.g. in the form of periodical fees, from consumers. This income is rather limited, however, and the cost study corrects for transfers in an attempt to measure the social cost.[23] Other model parameters that appear in derivations or results include merchant's production cost (γ), distance costs (t), the fixed costs involved in accepting (K) and (k) adopting cards, and finally the distributions of consumer (b_B) and merchant benefits (b_S). Some of these parameters, notably the cost parameters, can be estimated from the cost study data. Others such as the distribution of consumer benefits require ad hoc assumptions. The key model parameters are summarized in Table I.

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[22] I also include the co-branded Visa/Dankort in this category.

Table I: Estimates of model parameters

Parameter	Estimate
γ	31.0
t	3.6
K	0.044
c_C	0.043
c_D	0.206
$b_{S,max}$	0.498
$b_{S,min}$	-0.341
$b_{B,max}$	0.999
$b_{B,min}$	-0.515

The parameter values are obtained from the data as follows. Thinking of the model as describing a single transaction, the choice of γ is essentially a choice of transaction size while the choice of t determines the profit margin. According to the cost study, the average transaction size is 34.6 euros[24]. Since the merchant price is close to $\gamma + t$, I choose estimates of $\gamma = 31.0$ and $t = 3.6$, corresponding to a markup of about 10%. In the model, K corresponds to the total fixed cost, but the model describes a situation in which there is a unit mass of transactions. The logical counterpart when thinking of a single transaction is to compare the merchant fixed costs to the total value of cash and card payments and the multiply the average transaction size. The total value of cash (20.3 billion) and Dankort payments (34.1 billion) is 54.4 billion according to table 1 in the cost study, while merchant fixed costs are 101.9 million according to (Jacobsen and Pedersen, 2012). Part of this cost, however, is fees of 33.1 million paid to banks, which must be subtracted. For a payment of average size, this produces a value of $K = 0.044$.

The parameters c_C and c_D reflect banks' marginal costs of cash and card payments. Since banks' production functions are not observable, the most obvious proxy for these figures is the average variable cost. The use of this proxy is correct in the case of constant marginal costs. The empirical evidence presented in Schmiedel et al. (2012) suggest that this may not be an unrealistic assumption.[25] According to Jacobsen and Pedersen (2012), issuing banks' variable cash-related costs are 120.3 million. The total variable costs for issuing and acquiring banks are somewhat harder to obtain as one cannot simply add their individual costs. This is because there are fee payments among issuers (i.e. consumer banks) and acquirers (i.e. merchant banks) so adding costs would entail some double-counting. If one corrects for such fees, the total variable cost of issuers and acquirers is 42.6 million.[26] Dividing the total average variable cost by the total value of card and cash transactions respectively and then multiplying by the average transaction size, I arrive at average variable costs of 0.032 in the case of cards and 0.206 in the case of cash.

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[23] In this sense, social cost is narrowly defined to mean real production cost. There are other social costs related to the use of cash, for example its use in criminal activity, which are not taken into account.

[24] Costs are stated in euros since this is presumably a more familiar unit than the Danish krone. The Danish krone is pegged to the euro at an exchange rate of about EUR 1 = DKK 7.43 the average transaction size in Danish currency is 257 kroner. Minor rounding errors may appear as calculations were initially done in kroner.

It is also instructive to look at the actual fee income that banks earn in order to ascertain whether the assumption that banks do not charge consumers for payment services is satisfied in the data. Note that the critical assumption is that consumers do not pay transaction fees. The data does not reveal the source of banks fee income (whether transaction fees, periodic fees, or fees initially paid to obtain a card), but in any case the total fee income is so low as to be negligible. Banks' total fee income from households for the national debit card was 11.0 million in 2009. To put this number in perspective, there were 4.2 million issued cards of this type, implying that average annual fee income per card was about 2.5 euros. More generally, banks did not make much revenue on payment services. As an example, their income from providing cash services was 50.2 million, much less than their cost of providing these services.

The distributions of benefits are more difficult to parametrize. Merchant benefits b_S can be interpreted as the marginal savings (or cost) from a card payment relative to a cash payment. I estimate the average value of b_S at 0.078. I arrive at this number by calculating the difference in merchants' marginal cost of receiving cash and cards for a payment of average size.[27] I treat the estimate as the midpoint of a uniform distribution and thus let $b_{S,min} = 0.078 - x$ and $b_{S,max} = 0.078 + x$. A distribution for b_B can be determined in the same way. The cost study also makes a calculation of the costs a consumer has (e.g. time spent) making cash and card transactions respectively. For a transaction of average size, a consumer's cost consumers has costs of 0.104 when paying by card and euros for cash and 0.242 when paying with cash. For a transaction of average size this means that consumers enjoy benefits of 0.138 by paying with Dankort. I therefore set $b_{B,min} = 0.138 - y$ and $b_{B,max} = 0.138 + y$.

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[25] See, for instance, chart 2 in the paper, which depicts the relationship between average unit costs and payments per capita. The lines are downward sloping at a decreasing rate which is consistent with how unit costs would evolve if marginal costs were constant.

[26] This figure cannot be directly found the cost study or related papers. I have obtained the underlying data from one of the authors to calculate the figure.

[27] Figures for merchant's variable costs are provided in (Jacobsen and Pedersen, 2012), which itself is based largely on a working paper (only published in Danish) by Jacobsen. From that one can derive merchants' marginal cost functions for cash and Dankort payments can be written as $mc_D = 0.094 + 0.0027V$ and $mc_C = 0.102 + 0.0002V$, where V is the transaction value. The estimate is found by inserting the average transaction size in the place of V, and taking the difference between the marginal cost estimates for cash and cards.

The values of x and y are chosen such that the fraction of merchants accepting Dankort and the fraction of consumers preferring to pay by Dankort match real figures. About 95% of all merchants accept payments by Dankort. Since the total fraction of card payments (by value) is 62.7%, the fraction of consumers preferring to pay using Dankort is set at 66% (= 0.627/0.95). y can then be found first by solving the following equation for y:

$$1 - H(0) = \frac{b_{B,max}}{b_{B,max} - b_{B,min}} = \frac{b_{B,mid} + y}{2y} = 0.66 \tag{1.31}$$

Since $m = 0$ in the case of the Dankort, the merchant threshold is

$$b_S \geq b_S^\star = -E[b_B | b_B \geq 0] + \frac{3t\left(1 - \sqrt{1 - \frac{2K}{t}}\right)}{1 - H(0)} \tag{1.32}$$

This can be calculated based on the found parameter estimates, and x is then set so as to satisfy

$$1 - H(b_S^\star) = \frac{b_{S,max} - b_S^\star}{b_{B,max} - b_{B,min}} = \frac{b_{S,mid} + x - b_S^\star}{2x} = 0.95 \tag{1.33}$$

The obtained parameter estimates indicate that there is more heterogeneity in consumer benefits than merchant benefits. Another point of interest is the merchant acceptance threshold implied by the model, which evaluates to -0.30, implying that a merchant would accept card payments even if it increased costs relative to receiving payment pay cash by 0.30 for an average payment or by 0.86% in percentage terms.

1.4.2. Optimal interchange fees

The unconstrained optimal merchant fee follows directly from the parameter estimates. It is:

$$m_{opt} = c_C - c_D = 0.043 - 0.206 = -0.163 \tag{1.34}$$

In proportional terms this corresponds to an optimal merchant fee of -0.47%. Total acquiring costs for the Dankort, corrected for (i.e. not including) fees by paid acquirers to issuers, are estimated at 11.7 million[28], which corresponds to acquiring costs of just 0.03%. Hence, the implied optimal interchange fee is -0.50%. What informs such a low, even negative fee? Recall that $m_{opt} = c_C - c_D$. The main explanation for the low fee is to be found in banks' high net costs of providing cash services, c_D. Banks' revenues from cash services are negligible, but their costs are substantial. This effectively means that banks are subsidizing the use of cash, and it is this tendency that a social planner seeks to counteract by imposing a negative interchange fee. Some further analysis, however, shows that the optimal fee is not the only optimal fee; in derivations, I assumed an interior solution, but in practice all merchants accept cards at the optimal fee, and at higher fees as well (see Figure 1.2). Imposing such a low fee is therefore not the only way of reaching the optimal fee: A whole interval of fees would accomplish this task.

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[28] This estimate is based on data collected as part of the Danish cost study, but which cannot be directly found in

It is also possible to calculate the privately optimal interchange fee as predicted by the model given the parameter choices. In the case of no fixed costs, for instance, the privately optimal merchant fee is 1.21%. While this figure relies on the arbitrary assumption of uniformly distributed benefits, it is not unrealistic when compared to the actual fee levels observed in countries where fee levels are not regulated.

This fee can be contrasted with fees obtained by alternative methods. While it is not transparent how banks or card networks set interchange fees, a common method appears to be that issuers must be compensated for bearing certain costs that are considered to benefit the merchant side of the market (Börestam and Schmiedel, 2011). These costs include, as a minimum, operating costs related to processing payments, guaranteeing payments, and other security costs. An alternative, which some regulators use as a benchmark, is to apply the merchant indifference test. Based on the cost study data estimates of interchange fees based on each of these methods can be obtained.

The resulting interchange fee depends on which issuer costs are assigned to the merchant side of the market. The total cost of issuer services for the Dankort is estimated to be 79.6 million[29]. Of these, 15.8 million are purely related to transactions processing and guaranteeing payments. If these costs were to be covered, an interchange fee of 0.05% would be required. If all issuer costs were to be covered via the interchange fee, the implied fee would equal 0.23%, still a very low figure compared to actual interchange fees. Note that these calculation assume the total value of Dankort payments to be fixed. The model predicts that fewer payments would take place so presumably a somewhat higher interchange fee would be required.

The low interchange fee implied by the cost-based method is due mainly to two factors. First, the number of Dankort payments is large. Card usage per capita is high in Denmark, and the

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the publication. I have obtained the more granular data from the authors.

[29] Some of these costs are actually borne by the acquirer (there is only one acquirer of the Dankort), which in the Danish market also performs some services that are traditionally performed by issuers

vast majority of card payments are made using the Dankort. Second, the cost of producing Dankort payments is low. For instance, issuing banks' cost of producing Dankort payments is about 2.3 times their cost of producing payments with international debit cards even though the number of Dankort payments is roughly 20 times greater. If a similar cost-based analysis were to be performed for international debit cards, the implied interchange fee would be in the range 0.4%-0.7% depending on which issuer costs are passed on to the merchant side of the market.

The merchant indifference test calls for an interchange fee that makes the merchant no worse off by receiving payment by card. A practical challenge confronting this test is that merchant's marginal cost depends on the transaction value, and so a unit or percentage fee cannot on its own achieve indifference. However, the following marginal cost functions for cash and Dankort can be derived from the cost data in Jacobsen and Pedersen (2012):

$$mc_D = 0.094 + 0.0027V \tag{1.35}$$

$$mc_C = 0.102 + 0.0002V \tag{1.36}$$

It follows that that way to make a merchant indifferent is to impose a fee of:

$$a_{id} = -0.008 + 0.0025V \tag{1.37}$$

This implies an interchange fee of 0.25% less a small unit payment. Since the cost study also contains data on other, less widely-used cards, similar calculations can be performed for these. For example, for international debit cards the marginal cost equation is:

$$a_{id} = 0.101 + 0.0051V \tag{1.38}$$

In this instance, the variable part of the marginal cost includes the existing interchange fee, the level of which is not publicly known. However, an upper bound estimate can be obtained by assuming that all of merchants' fees paid on international debit cards (4.24 million according to table 5.7 in Danmarks Nationalbank (2011)) are interchange fee payments. Since the value of international debit card payments was 915 million, an the average interchange fee is at most 0.46%. This would imply a marginal cost function, exclusive of interchange fees, of $a_{id} = 0.101 + 0.0006V$. It follows that the optimal interchange fee according to the merchant indifference test should therefore be on the order of:

$$a_{id} = -0.007 + 0.0021V \tag{1.39}$$

Interestingly, this implied interchange fee level is close to the interchange fee of 0.20%, which the European Commission has agreed upon with the large card networks in Europe and the fee level ceiling for debit cards in the proposed regulation of interchange fees.

When calculating the value of the social planner's objective function, it turns out that the choice between different benchmarks for interchange fees may not make much of a difference. The reason is that for low enough merchant fees, the merchant acceptance threshold may lie below the numerical estimate for $b_{S,min}$. In that case all merchants accept cards, and reducing the merchant fee further has no welfare consequences. When fixed costs are included, the value of m at which this occurs is -0.32 (-0.12%), but if fixed costs are excluded the value is 1.17 (0.46%). Below these values the social planner's objective function takes on a constant value. Merchant profits and the value of the social objective function as a function of the merchant fee are depicted in Figure 1.2.

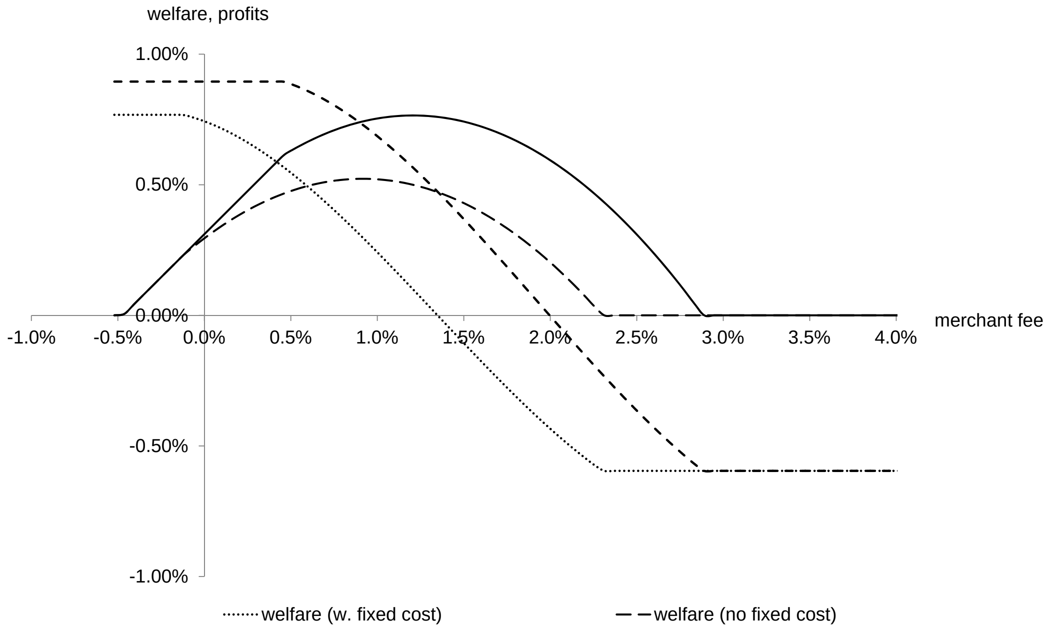

Figure 1.2: Welfare and profits (without surcharging)
The figure shows welfare and profits as a function of the merchant fee, under the assumption that merchants do not surcharge the fees. Welfare is defined as the total benefits accruing to consumers and merchants from card payments (relative to cash payments) less the total costs of producing all payments. It is measured here as a fraction of transaction value. The upper lines represent welfare, the lower lines profits. Welfare and profits are shown under both the assumption of no merchant fixed costs and merchant fixed costs. The flat portions of the lines represent areas where either all (to the left) or no (to the right) consumers use cards.

1.4.3. Surcharging

When surcharging is permitted, the model does not provide simple answers to whether merchants will, in fact, surcharge. The numerical analysis highlights this difficulty. To illustrate this with an example, the equilibrium outcome for a pair of average merchants ($b_S = 0.5825$) is to accept cards and not surcharge if $m = -1$, to accept cards and surcharge if $m = 2$, not to accept cards if $m = 5$. This might indicate a natural progression from not surcharging at low fees, to surcharging at higher fees, and then to not accept cards when fees reach a certain limit. Such a conclusion does not hold for all combinations of m and b_S. When $(m, b_S) = (-0.2, -2.3)$, for instance all three symmetric outcomes are equilibria. If $(m, b_S) = (4.7, 2.6)$, there are two asymmetric equilibria in which one merchant accepts cards and surcharges and the other does not accept cards. Increase b_S slightly, say to 2.66, and there are no equilibria, whereas both merchants surcharge if $b_S = 2.7$.

At the socially optimal fee derived under the assumption of surcharging being prohibited, the equilibrium is for all merchants with $b_S \leq 0.70$ is to accept cards and not surcharge. However, for merchants who enjoy greater benefits the equilibrium outcome is an asymmetric one in which one merchant surcharges and the other does not. The implication is that at that fee, all merchants accept cards, and some merchants surcharge whereas others do not. At somewhat higher fees such as 0.20% (0.54 in absolute value), which is close to the fee according to the merchant indifference test, most merchants ($b_S > -1.83$) accept cards and surcharge. Merchants who enjoy lower benefits do not accept cards at all. At the privately optimal fee (i.e. the optimal fee when surcharging is not permitted), merchants do not accept cards for $b_S \leq 0.63$, but accept cards and surcharge when $b_S > 0.72$. In a small interval in between there are two equilibria in which one merchant does not accept cards, and the other accepts cards and surcharges.

An overview of the equilibria of the model is provided in Figure 1.3. It depicts the regions of (m, b_S)-combinations for which different types of equilibria in the merchant acceptance game occur. Shaded regions indicate the presence of equilibria.

Merchants do not accept cards if merchant fees are high and they enjoy low benefits. When merchant fees are positive, merchants will generally surcharge if permitted, though there are also cases with no or asymmetric equilibria. When merchant fees are slightly negative, merchant who enjoy the lowest benefits will still surcharge. The predominant equilibria when merchant fees are negative, though, is to accept cards and not surcharge in the case of low merchant benefits or for one merchant to surcharge and for the other not to surcharge.

Actual fees will typically be in, say, the 0%-2%-region, and so the model suggests that one mainly should observe two types - cash acceptance or card acceptance with surcharging - with the degree of card acceptance falling as fees increase. The point about surcharging is to some extent counterfactual since, even when surcharging is permitted, many retailers choose not to surcharge. Empirical studies of surcharging behavior do, though, indicate that large retailers surcharge so

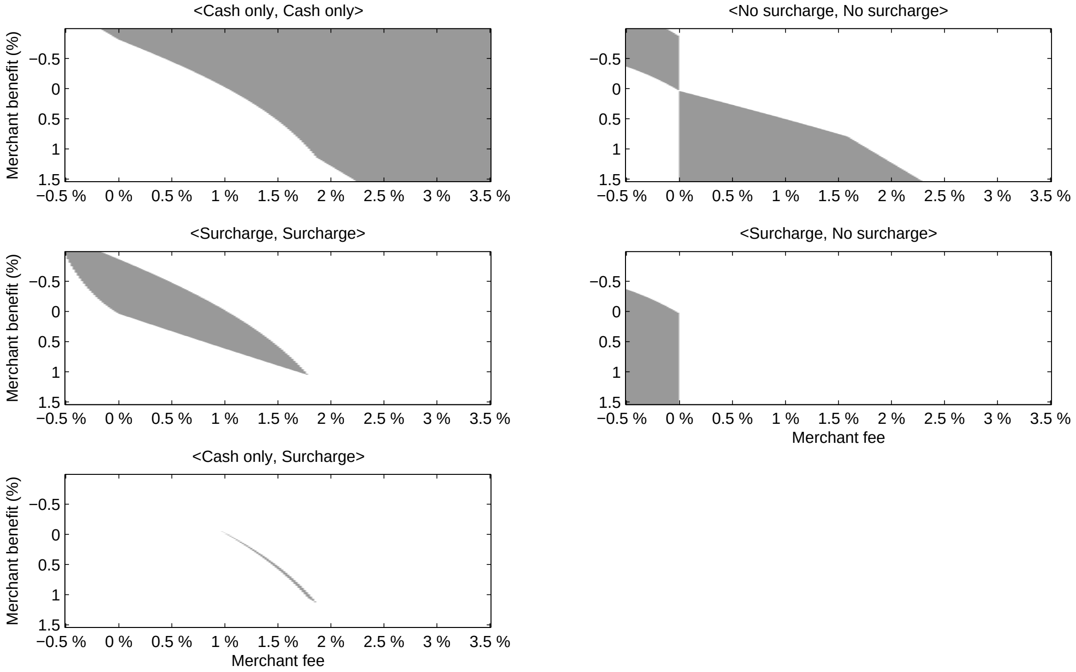

Figure 1.3: Equilibria in model with surcharging
The shaded area of each figure represents the combinations of merchant fees (x-axis) and merchant benefits (y-axis), both expressed as a percentage of average transaction value, for which the response profile in question (see figure titles) is a Nash equilibrium. As an example, the uppermost panel to the left shows that the optimal response of merchants is to only accept cash when merchants benefits are low and/or when merchant fees are high.

even if the fraction of retailers surcharging is limited, the fraction of all sales on which surcharging is applied can be relatively large.

To gauge welfare in the surcharging case against welfare in the no-surcharging case, one can evaluate the value of the social planner's objective function under the assumption that merchants face only a choice between not accepting cards and accepting cards and surcharging. The presence of e.g. situations without any equilibria makes it impossible to evaluate the objective function when all of merchants' three options are available.

If one compares welfare under surcharging and no surcharging, the welfare effects of surcharging depend on the merchant fee applied. For negative merchant fees welfare is greater when surcharging is applied. This is because surcharging of negative fees, which is equivalent to giving rebates for card usage, induces more consumers to use cards which benefits card-accepting merchants who, on average, are better off with greater card usage. It may not be obvious from visual inspection of Figures 1.2 and 1.4, but the opposite is the case for positive merchant fees for which welfare is higher when surcharging does not take place.

Comparing Figure 4 to Figure 2 also shows that banks' privately optimal fee is lower when surcharging takes place than when it does not, as are bank profits. An interesting issue is how

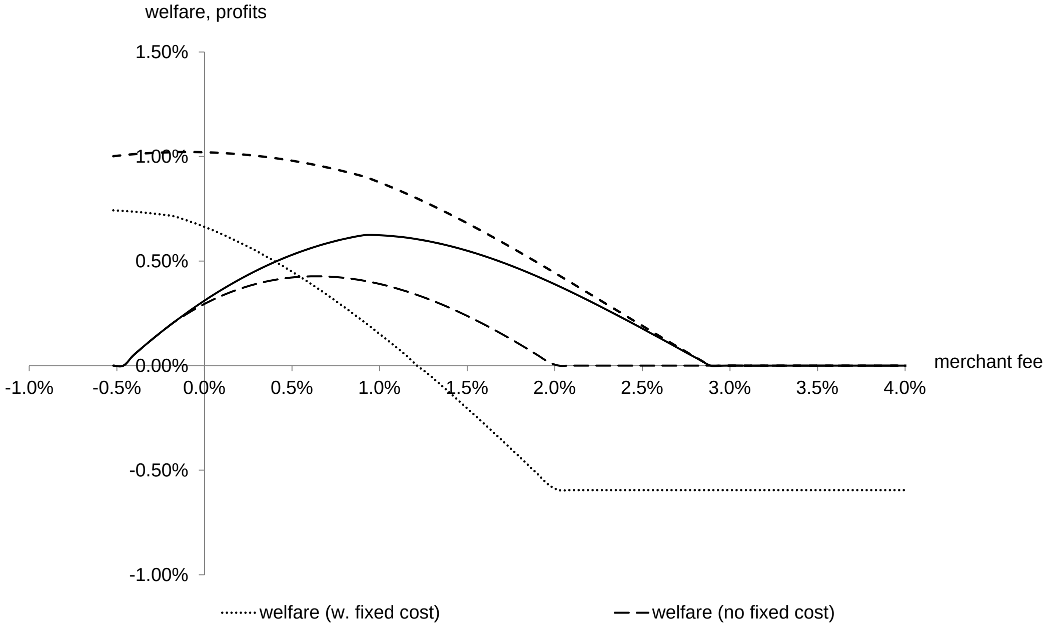

Figure 1.4: Welfare and profits (with surcharging)
The figure shows welfare and profits as a function of the merchant fee, under the assumption that merchants surcharge the fees. Welfare is defined as the total benefits accruing to consumers and merchants from card payments (relative to cash payments) less the total costs of producing all payments. It is measured here as a fraction of transaction value. The upper lines represent welfare, the lower lines profits. Welfare and profits are shown under both the assumption of no merchant fixed costs and merchant fixed costs. The flat portions of the lines represent areas where either all (to the left) or no (to the right) consumers use cards.

the socially optimal fee compares to the privately optimal fees with and without surcharging. On the one hand, we know that surcharging lowers welfare for a given (positive) merchant fee, but, on the other hand, the privately optimal merchant fee is lower when surcharging is permitted. It is at least plausible, therefore, that surcharging will increase welfare. This turns out to be the case, though the improvement in welfare is numerically very small.

The implication is that surcharging might improve welfare if merchant or interchange fees are not regulated. However, at low fees or close to the optimal fee, the analysis suggests that surcharging would reduce welfare. At low interchange fees, welfare would be greater in the absence of surcharging, and while welfare would in principle be higher with surcharging for negative fees, Figure 1.3 illustrates that merchants would, in fact, not surcharge at such fees.

1.4.4. Consumer adoption costs

When both consumers and merchants face adoption costs there are two card usage equilibria, one with a high degree of card acceptance among merchants and consumers and one with low acceptance. The first step in identifying these equilibria is to select a value for consumer adoption costs k. I use an estimate is $k = 0.067$.[30] Given that value it is possible to find equilibria for different values of m. For reasonable values of m there will be two equilibria. The numerical analysis shows that both bank profits and the value of the social planner's objective function are always highest in the equilibrium where card usage is high. The merchant fee that maximizes profits in that equilibrium is 1.04% as a percentage of the transaction value. The fixed points of the function $f(b_S)$ are depicted in Figure 1.5 for three different values of the merchant fee.

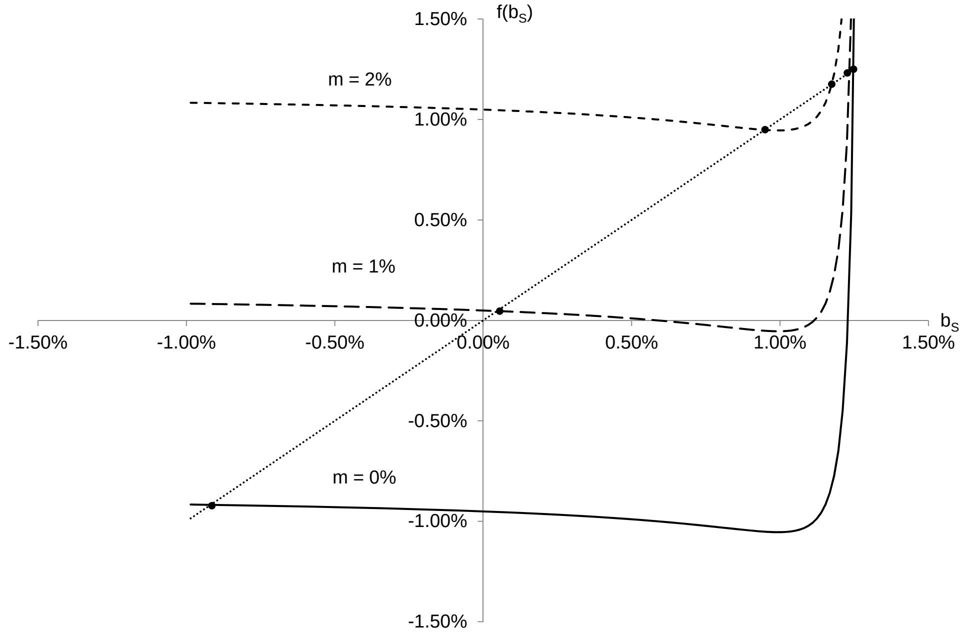

Figure 1.5: Fixed points with consumer and merchant fixed costs
The figure depicts, for three different merchant fees, values of the threshold of the merchant benefits (stated in percentages of transaction value) for which the fraction of merchants accepting cards is consistent with the fraction of consumers using cards (and vice versa). There are two fixed points for each merchant fee, the leftmost corresponding to an equilibrium with high card usage and acceptance and the rightmost corresponding to an equilibrium with low card usage and acceptance.

This figure is typical of how the two fixed points are located. To understand the figure, consider first the case of b_S being lower than at the first equilibrium point. A low value of the merchant threshold b_S corresponds to many merchants accepting cards. In that case, many users would also like to use cards. The marginal card user therefore attaches a low value to using cards relative to cash, but in that case merchants are less inclined to compete for card users. So for the value of the consumer threshold, i.e. the value of b_B that is consistent with the particular value of b_S, $f(b_S) > b_S$, which means that fewer merchants will accept cards. As b_S increases in value, two effects are at play. First, the marginal card user attaches more value to being able to pay by card, and merchants compete more vigorously for these with a resulting decrease in $f(b_S)$. This effect dominates initially. As there are fewer card users, however, merchants' fixed cost must be spread across fewer users, and ultimately this effect dominates.

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[30] According to survey data, a typical consumer makes about 400 transactions per year. Supposing that banks did charge consumers their official list prices of 26.9 euros (=200) kroner, that would correspond to a value of $k = 0.067$ if such prices were charged, since k can be viewed as a consumer's average fixed cost.

In the high card usage (low b_S) equilibrium, 58.0% of consumers use cards and 55.9% of merchants accept cards. If merchants and consumers were to find themselves in the low card usage equilibrium, the fraction of merchants and consumers accepting and using cards would just be 8.5% and 13.8%. These figures contrast with merchant acceptance at the fee, which maximizes the social planner's welfare function assuming that consumers and merchants end up in the high card usage equilibrium. That fee is -0.17, and is associated with 61.6% of consumers using cards and all merchants accepting cards.

The model is static, but if one were to think of the model in dynamic terms, only the equilibrium with high card usage would be a stable equilibrium. If, initially, the merchant acceptance threshold were less than at the first equilibrium point, the number of merchants accepting cards would decrease due to the mechanics described above: Many consumers would use cards, and this would actually make it less attractive for merchants to accept cards, corresponding to an increase in the merchant threshold. The opposite would happen for values of b_S between the two equilibrium points. Few consumers would be using cards, but since these consumers would be those enjoying high card benefits, more merchants would accept cards in order to attract them and the merchant acceptance threshold would decline. To the right of the second equilibrium point the situation would diverge towards an outcome without any card usage.

1.5. Conclusion

In this paper I develop a model of interchange fees for a particular, but empirically relevant price structure for payment services. In doing so, I show that that a number of conclusions in the earlier literature are altered, sometimes entirely reversed, when banks do not charge transaction fees. Among the key results are the following: (1) lower interchange fees will lead to greater card usage; (2) banks, if unregulated, choose a fee which exceeds the social optimum, and the outcome is an excessive use of cash; and (3) a cost-based optimal fee can be calculated and provides a useful benchmark for evaluating actual interchange fees.

The paper suggests some avenues for further research. An interesting question is how payment services are priced in the first place. I discuss why a price structure without transaction fees might be an equilibrium outcome, but the question is clearly deserving of a more thorough examination.

For example, might banks alter their pricing behavior if interest rates are low for an extended period of time? Recall that one argument why payment services might be free is that these are used to attract deposits which provide cheap funding for banks.

The model does not focus on the case where consumers face negative fees, e.g. in the form of rewards or cash-backs, though that is also a possible outcome when interchange fees are sufficiently large. Many cards, especially credit cards, have higher interchange fees and offer certain "benefits" (e.g. insurance, frequent flyer points, etc.) to consumers. However, that raises another question: Why do these card "benefits" in many cases not come in the form of negative fees, but rather in the form of other goods, which would seem to be less valuable than an equivalent amount of cash? I would tentatively suggest that card benefits are used as a screening device. In particular, the benefits promised by credit cards often appear to be relatively more valuable to wealthier individuals. It seems plausible that card networks specifically seek to attract such individuals in order to be able to charge merchants higher card fees (as losing business from these individuals is particularly costly). It would be interesting to develop a model of interchange fees which considers such a screening mechanism. This may also help explain why there is a plethora of card types (e.g. a single card brand having different "qualities" of cards such as e.g. "platinum" cards) even though all cards basically perform the same payment function.

1.6. Appendix

Proof of Lemma 1

The proof mirrors that in Rochet and Tirole (2002), except for the fact that fixed adoption costs are included in this derivation. The inclusion of the proof is useful for an additional reason, namely that the derivation of surcharging equilibria follows a similar structure, but a number of intermediate calculation steps are not shown in that derivation.

Assume initially that both merchants accept cards, and set prices p_1 and p_2 in order to maximize profits. For a merchant pair, let x denote the market share of one of the merchants, say merchant 1. In that case, the market share is found by solving:

$$p_1 + xt = p_2 + (1-x)t \Leftrightarrow x = \frac{1}{2} + \frac{p_2 - p_1}{2t} \tag{1.40}$$

The resulting merchant profits are:

$$\pi_1 = \left(\frac{1}{2} + \frac{p_2 - p_1}{2t}\right)(p_1 - \gamma - (m - b_S)(1 - H(b_B^\star)) - K \tag{1.41}$$

$$\pi_2 = \left(\frac{1}{2} + \frac{p_1 - p_2}{2t}\right)(p_2 - \gamma - (m - b_S)(1 - H(b_B^\star)) - K \tag{1.42}$$

In words, profits are the product of market share times profit margin, less fixed costs. Note that merchant fees and card benefits are only paid and received for the fraction $1 - H(b_B^\star)$ of consumers, which prefer to pay by card. Recall that $b_B^\star$ denotes the threshold above which consumers prefer the use of payment cards to cash. This is assumed to be zero throughout most of the paper, but here the general case is considered.

The next step is to find the profit maximizing prices. Solving for the first-order condition w.r.t. price results in the following price for merchant 1:

$$p_1 = \frac{1}{2}[t + p_2 + \gamma + (1 - H(b_B^\star))(m - b_S)] \tag{1.43}$$

Since merchant 2 solves a symmetrical problem, the expression for p_2 is identical, only with subscripts interchanged. One can therefore solve for p_1 and p_2:

$$p_1 = p_2 = t + \gamma + (1 - H(b_B^\star))(m - b_S) \tag{1.44}$$

Inserting the price expressions into the profit function produces:

$$\pi_1 = \pi_2 = \frac{1}{2}t - K \tag{1.45}$$

To ensure that both merchants accepting cards is an equilibrium, it must be the case that neither has an incentive to deviate and accept cash only. To establish the conditions under which this will be the case, suppose therefore that merchant 2 only accepts cash. Letting x_C and x_D denote the market shares among cash and card users respectively, merchant 2 will obtain market shares of:

$$(1 - x_D) = \frac{1}{2} + \frac{p_1 - p_2}{2t} \tag{1.46}$$

$$(1 - x_C) = \frac{1}{2} + \frac{p_1 - p_2 - E[b_B|b_B^\star]}{2t} \tag{1.47}$$

where the market share among card users is found by comparing the consumers' cost of trading with merchant 1 and paying by card, which is $p_1 + tx_C - b_B$, with the cost of trading with merchant 2, which is $P_2 + (1 - x_C)t$, and finally integrating over the interval $[b_B^\star, b_{B,max}]$.

Profits are:

$$\begin{aligned} \pi_1 = H(b_B^\star)\left(\frac{1}{2} + \frac{p_2 - p_1}{2t}\right)(p_1 - \gamma) \\ +(1 - H(b_B^\star))\left(\frac{1}{2} + \frac{p_2 - p_1 + E[b_B|b_B \geq b_B^\star]}{2t}\right)(p_1 - \gamma - m + b_S) - K \end{aligned} \tag{1.48}$$

$$\pi_2 = \left(\frac{1}{2} + \frac{p_1 - p_2 + (1 - H(b_B^\star))(-E[b_B|b_B \geq b_B^\star])}{2t}\right)(p_2 - \gamma) \tag{1.49}$$

The associated first-order conditions are:

$$p_1 = \frac{1}{2}\left(t + \gamma + p_2 + (1 - H(b_B^\star))(m - b_S + E[b_B|b_B \geq b_B^\star]\right) \tag{1.50}$$

$$p_2 = \frac{1}{2}\left(t + \gamma + p_1 + (1 - H(b_B^\star))E[b_B|b_B \geq b_B^\star]\right) \tag{1.51}$$

Solving for prices:

$$p_1 = t + \gamma + \frac{1}{3}(1 - H(b_B^\star))\left(2(m - b_S) + E[b_B|b_B \geq b_B^\star]\right) \tag{1.52}$$

$$p_2 = t + \gamma + \frac{1}{3}(1 - H(b_B^\star))\left(m - b_S - E[b_B|b_B \geq b_B^\star]\right) \tag{1.53}$$

This implies profits for merchant 2 of:

$$\begin{aligned}\pi_2 = &\left(\frac{1}{2} + \frac{\frac{1}{3}(1 - H(b_B^\star))(m - b_S - E[b_B|b_B \geq b_B^\star])}{2t}\right) \\ &\times \left(t + \frac{1}{3}(1 - H(b_B^\star))(m - b_S - E[b_B|b_B \geq b_B^\star])\right)\end{aligned} \tag{1.54}$$

Hence, the condition required for a card acceptance equilibrium is that the above is less than or equal to $\frac{1}{2}t - K$. Examining this inequality and solving for b_S gives:

$$b_S \geq m - E[b_B|b_B \geq b_B^\star] + \frac{3t(1 - \sqrt{1 - \frac{2K}{t}}}{1 - H(b_B^\star)} \tag{1.55}$$

Proof of Proposition 1

To show the existence of equilibria, one can appeal to Brouwer's fixed point theorem which requires a continuous function $f : S \to S$ on a non-empty, convex, compact subset of a finite-dimensional normed linear space. Continuity of f follows from the continuity of $G(b_S)$ and $H(b_B)$ which is assumed. The set $S = [b_{S,min}, b_{S,max} - \epsilon]$ is clearly convex, closed and bounded. Being a subset of the set of real numbers, the set is therefore compact. Hence, the only remaining requirement of Brouwer's fixed point theorem is that $f(b_S)$ maps S into itself, and imposing the condition stated in the proposition ensures exactly that.

Proof of Proposition 2

With $k = 0$ there is only one equilibrium in which cards are used. The fraction of individuals using payment cards is $1 - H(0)$. Applying the result from Proposition 1, the fraction of merchants accepting cards is:

$$1 - G\left(m - E[b_B \mid b_B \geq 0] + \frac{3t\left(1 - \sqrt{1 - \frac{2K}{t}}\right)}{1 - H\left(0\right)}\right) \tag{1.56}$$

The fraction of card payments is consequently

$$\mu(m) = (1 - H(0))\left(1 - G\left(m - E[b_B \mid b_B \geq 0] + \frac{3t\left(1 - \sqrt{1 - \frac{2K}{t}}\right)}{1 - H\left(0\right)}\right)\right) \tag{1.57}$$

Since $G\left(m - E[b_B \mid b_B \geq 0] + \frac{3t\left(1 - \sqrt{1 - \frac{2K}{t}}\right)}{1 - H(0)}\right)$ is increasing in m, it follows that card usage is decreasing in m.

Proof of Lemma 2

The expression, which simply says that banks in optimum equate marginal revenues and marginal costs, follows from solving for the banks' first-order condition and rearranging terms.

The second-order condition requires that

$$2g(m) - g'(m)(m - c_C + c_D) < 0 \tag{1.58}$$

Inserting the expression for m, one can verify that an increasing hazard rate $\frac{g(b_S)}{1-G(b_S)}$ or, equivalently, that a decreasing inverse hazard rate is sufficient condition for this inequality to be satisfied.

Proof of Corollary 1

The transportation cost appears in the expression for the merchant fee as part of the following term

$$3t\left(1 - \sqrt{1 - \frac{2K}{t}}\right) \tag{1.59}$$

To prove the assertion that the m is increasing in t, we first observe that the above expression is decreasing in t. To see this, one can differentiate w.r.t. to t and rearrange terms. Assuming the derivative to be negative can then be shown to be equivalent to the condition $-2t \leq 3K$ which clearly is true.

Next, we have assumed the hazard rate $\frac{g(\cdot)}{1-G(\cdot)}$ to be increasing. Now, as t increases, it follows that the hazard rate decreases which implies that the term found in the expression for the merchant fee increases.

Proof of Proposition 3

Differentiation of the social objective function w.r.t. m and rearranging slightly results in the following expression

$$\int_{0}^{b_{B,max}} b_B dH(b_B) + (1 - H(0))\left(m - E[b_B | b_B \geq 0] - c_C + c_D\right) = 0 \tag{1.60}$$

Dividing by $1 - H(0)$ and $-g(m - E[b_B|b_B \geq 0])$ and solving for m gives

$$m = c_C - c_D \tag{1.61}$$

The second-order condition is automatically satisfied at this value of m, independent of any distributional assumptions. To see this, note that the second derivative of the objective function can be written as

$$g'(b_s^\star)(E[b_B \mid b_B \geq 0] + b_S^\star - c_C + c_D) - g(b_S^\star) \tag{1.62}$$

At the socially optimal fee $b_S^\star = c_C - c_D + E[b_B \mid b_B \geq 0]$. Hence, the second derivative reduces to $-g(b_S^\star)$ which is negative.

Proof of Proposition 4

This is an immediate consequence of comparing the expressions found in Lemma 2 and Proposition 3.

Proof of Proposition 5

If m is set such that $b_S > m - E[b_B|b_B \geq 0] + \frac{3t(1-\sqrt{1-\frac{2K}{t}}}{1-H(0)}$, no merchant accepts card and no card payments take place. For any merchant fee that satisfies $b_S \leq m - E[b_B|b_B \geq 0] + \frac{3t(1-\sqrt{1-\frac{2K}{t}}}{1-H(0)}$, all merchants accept cards, and the fraction of card payments is $1 - G(0)$, which is independent of the merchant fee. The merchant acceptance threshold thus determines an upper bound for the interval of optimal merchant fees; this fee is also the profit maximizing fee for banks.

Reducing the merchant fee leaves the social objective function unchanged, at least until a point is reached at which banks' rationality constraint is no longer satisfied. That point determines the lower bound of the interval.

Proof of Lemma 3

Assume that merchant 1 accepts cards and surcharges. If both merchants accept cards and surcharge, they earn profits of $\frac{1}{2}t - K$. This can be shown by setting the adoption threshold at $b_B^\star = m$, removing the $-m$-term from the merchant profit functions, and then redoing the derivations. We must therefore establish the conditions under which merchant 2 is no better off by not accepting cards.

With surcharging, the fraction of consumers who always pay using cash when they can is $G(m)$. Among these, merchant 2 enjoys a market share of:

$$1 - x_D = \frac{1}{2} + \frac{p_1 - p_2}{2t} \tag{1.63}$$

Consumers in the remaining part of the population are indifferent between the two merchants whenever:

$$p_1 - b_B + m + tx_C = p_2 + t(1 - x_D) \tag{1.64}$$

Integrating over all consumers with benefits in the interval $[m, b_{B,max}]$ gives a market share among card users (i.e. those who use cards when possible) of:

$$1 - x_C = \frac{1}{2} + \frac{p_1 - p_2 - E[b_B|b_B \geq m] + m}{2t} \tag{1.65}$$

This implies profit functions of:

$$\begin{aligned} \pi_1 = H(m)\left(\frac{1}{2} + \frac{p_2 - p_1}{2t}\right)(p_1 - \gamma) \\ +(1 - H(m))\left(\frac{1}{2} + \frac{p_2 - p_1 + E[b_B|b_B \geq m] - m}{2t}\right)(p_1 - \gamma + b_S) - K \end{aligned} \tag{1.66}$$

$$\pi_2 = \left(\frac{1}{2} + \frac{p_1 - p_2 + (1 - H(m))(-E[b_B|b_B \geq m] + m)}{2t}\right)(p_2 - \gamma) \tag{1.67}$$

Deriving the two merchants' first-order conditions and solving for p_1 and p_2 gives:

$$p_1 = t + \gamma + (1 - H(m))\left(-\frac{2}{3}b_S + \frac{1}{3}E[b_B|b_B \geq m] - \frac{1}{3}m\right) \tag{1.68}$$

$$p_2 = t + \gamma + (1 - H(m))(-\frac{1}{3}b_S - \frac{1}{3}E[b_B|b_B \geq m] + \frac{1}{3}m) \tag{1.69}$$

Inserting these expressions into the second merchant's profit function and simplifying produces:

$$\pi_2 = \frac{1}{2t}\left[t + (1 - H(m))(-\frac{1}{3}b_S - \frac{1}{3}E[b_B|b_B \geq m] + \frac{1}{3}m)\right]^2 \tag{1.70}$$

Comparing this to the profit when both merchants accept cards and surcharge, one can show the no deviation condition to be:

$$b_S \geq m - E[b_B|b_B \geq m] + \frac{3t\left(1 - \sqrt{1 - \frac{2K}{t}}\right)}{1 - H(m)} \tag{1.71}$$

Proof of Proposition 7

For a given positive merchant fee, the fraction of payments made by cards is then greater under no surcharging if the following condition is satisfied

$$(1 - H(0))(1 - G(m - E[b_B|b_B \geq 0])) \geq (1 - H(m))(1 - G(m - E[b_B|b_B \geq m])) \tag{1.72}$$

It is evident from these expressions that more consumers use cards when surcharging is prohibited while more mercants accept cards when it is allowed. The latter follows from the fact that $E[b_B|b_B \geq m] \geq E[b_B|b_B \geq 0]$.

Adding and subtraction terms on the right-hand side gives

$$\begin{aligned}(1-H(0))(1-G(m-E[b_B|b_B\geq 0]))&\geq[(1-H(0))+(H(0)-H(m))]\\ \times[(1-G(m-E[b_B|b_B\geq 0]))+(G(m-E[b_B|b_B\geq 0])&-G(m-E[b_B|b_B\geq m]))]\end{aligned} \tag{1.73}$$

Simplifying and rearranging

$$\frac{G(m-E[b_B|b_B\geq m])-G(m-E[b_B|b_B\geq 0])}{1-G(m-E[b_B|b_B\geq m])}\geq\frac{H(0)-H(m)}{1-H(0)} \tag{1.74}$$

The expression on the left-hand side is the percentage decrease in the fraction of merchants accepting cards that would occur if surcharging were prohibited. The expression on the right-hand side equals the percentage decrease in the fraction of consumers using cards when surcharging is permitted.

Proof of Lemma 4

The expression is found by solving the banks' profit-maximization problem subject to the new rationality constraint.

Equilibria with surcharging

In this section I discuss merchants' choice of whether to accept cards and surcharge or whether to accept cards and not surcharge. The expressions found here are only used in the numerical analysis for identifying equilibria when surcharging is permitted.

As noted in the discussion of surcharging in the results section, merchants have three options at their disposal: (1) they can choose to accept only cash; (2) they can choose to accept cards without surcharging; and (3) they can accept cards and surcharge the merchant fee. The profits resulting from most of the strategies have already been discussed in lemma 1 and lemma 4. One case, however, has not been considered: When one merchant (say, merchant 1) accepts cards without surcharging while the other merchant also accepts cards, but surcharges. This case is discussed in this section, and the results are used to establish the type of equilibria which exist when each of the three options are available to merchants.

In this case there are three distinct classes of consumers for whom market shares must be calculated for each merchant. Assuming that $m > 0$, for consumers with a strict preference for cash, i.e. $b_B < 0$, merchant 1's market share is:

$$x=\frac{1}{2}+\frac{p_2-p_1}{2t} \tag{1.75}$$

Then there are consumers who will by card if transacting with merchant 1, but not with merchant 2. These are the ones who enjoy card benefits in the interval $[0, m)$. These consumers are indifferent between the two merchants when:

$$p_1 + tx - b_B = p_2 + (1 - x)t \tag{1.76}$$

Solving for x, and integrating over the relevant interval, one finds that merchant 1 enjoys a market share of:

$$\frac{1}{2} + \frac{p_2 - p_1 + E[b_B | 0 \leq b_B < m]}{2t} \tag{1.77}$$

Finally, there are those consumers who will pay by card at either merchant, whether surcharging is applied or note. These enjoy card benefits $b_B \geq m$, and are indifferent between the two merchants at

$$p_1 + tx - b_B = p_2 + (1 - x)t + m - b_B \tag{1.78}$$

The calculations could also be done under the assumption that $m < 0$. In that case the three relevant intervals of consumers would be $[b_{B,min}, m)$ (cash users), $[m, 0)$ (cash users when transacting with merchant 1, and card users when transacting with merchant 2) and $[0, b_{B,max}$ (card users). Among these types, merchant 1 has market share:

$$x = \frac{1}{2} + \frac{p_2 - p_1 + m}{2t} \tag{1.79}$$

Multiplying the market shares by profit margins for each class and weighing by the classes' proportion in the consumer population, one arrives at profits:

$$\begin{aligned} \pi_1 = H(0)(\frac{1}{2} + \frac{p_2 - p_1}{2t})(p_1 - \gamma) \\ +(H(m) - H(0))(\frac{1}{2} + \frac{p_2 - p_1 + E[b_B—0 \leq b_B < m]}{2t})(p_1 - \gamma + b_S - m) \\ +(1 - H(m))(\frac{1}{2} + \frac{p_2 - p_1 + m}{2t})(p_1 - \gamma + b_S - m) - K \end{aligned} \tag{1.80}$$

$$\begin{aligned} \pi_2 = H(0)(\frac{1}{2} + \frac{p_1 - p_2}{2t})(p_2 - \gamma) \\ +(H(m) - H(0))(\frac{1}{2} + \frac{p_1 - p_2 - E[b_B—0 \leq b_B < m]}{2t})(p_2 - \gamma) \\ +(1 - H(m))(\frac{1}{2} + \frac{p_1 - p_2 - m}{2t})(p_2 - \gamma + b_S) - K \end{aligned} \tag{1.81}$$

Finding for the first-order conditions and solving for p_1 and p_2 produces:

$$p_1 = t + \gamma + (H(m) - H(0))(-\frac{2}{3}b_S + \frac{2}{3}m + \frac{1}{3}E[b_B\text{—}0 \leq b_B < m]) + (1 - H(m))(-b_S + m) \quad (1.82)$$

$$p_2 = t + \gamma + (H(m) - H(0))(-\frac{1}{3}b_S + \frac{1}{3}m - \frac{1}{3}E[b_B\text{—}0 \leq b_B < m]) + (1 - H(m))(-b_S) \quad (1.83)$$

These expressions can be inserted into the profit function for merchant 2, the value of which must then be compared to $\frac{1}{2}t - K$. Doing this, one can find a expression which gives the values of of b_S, for which it does not pay off to deviate, but these are too complicated to gain much intuition from. Using derivations that parallel the ones above, one can similarly find merchant profits and prices under the assumption of negative merchant fees.

Bank Liquidity and the Interbank Market

ABSTRACT

Banks exchange liquidity in the money market to absorb payment shocks. In a well-functioning market, banks in need of liquidity should not pay a premium when borrowing. We combine data on bank reserves at the central bank and interest rates paid in the money market to study how bank liquidity affects interbank rates. Banks with scarce liquidity pay only marginally higher rates than do those with ample liquidity. However, during times of financial stress and when the need for liquidity is more pronounced, those short of liquidity pay a higher cost.

Keywords: Financial regulation; Interchange fees; Payments

JEL-classification: E42; G21; G28

2.1. Introduction

The financial crisis has spawned a considerable literature on the functioning of interbank markets. A common theme in this literature is whether the market allows banks to absorb liquidity shocks and allocate liquidity efficiently amongst themselves. Prior to the crisis, the view seems to have been that the money market functioned well. Analyzing the interbank money market during the crisis in the autumn of 1998, when Russia effectively defaulted on its sovereign debt and a rescue of the hedge fund Long-Term Capital Management took place, Furfine (2001, 2002) concludes that the market was robust. Rates did not stray from target or increased in variability, market volume actually increased, and there was little evidence of greater credit spreads due to heightened financial uncertainty. The crisis of 1998, however, was minor compared to the financial crisis which unfolded in 2007. In the 2007-2008 financial crisis and its aftermath, interest rate volatility spiked, and many banks resorted to using central bank facilities. The market, while not completely frozen, was stressed (Afonso et al., 2011).

This paper examines the functioning of the money market in a novel way. Now, there is a certain vagueness about what it means for a market to "function well". The nature of the interbank market, however, suggests a natural benchmark, namely whether a bank in need of liquidity pays a premium for liquidity when borrowing. To use an analogy from basic microeconomics, if there is no price discrimination, all individuals pay the same amount independent of their willingness to pay. The analogy is imperfect, however, because a loan is not standardized good: prices (interest rates) should differ across borrowers to reflect their credit risk. When trying to assess whether banks in need of liquidity pay higher rates, one must therefore control for credit risk.

The total amount of liquidity to be distributed in the interbank market is essentially fixed, at least in the absence of central bank intervention. A positive liquidity flow for one bank is a negative flow for another. Liquidity shocks thus affect the liquidity of individual banks, i.e. the distribution of liquidity, but not the total amount of liquidity available to banks. Hence, in the absence of frictions, banks faced with liquidity shocks should be able to absorb these by borrowing from those with surplus liquidity. Competition among the latter should push down interest rates until they equal the opportunity cost of lending funds. A bank faced with a liquidity shock therefore should not, controlling for other characteristics, pay a premium.

Our analysis couples transaction-level data on day-to-day interbank loans in the period from 2005 to 2013 with information on Danish banks' liquidity holdings with the central bank. A key element in our analysis is that, due to lower and upper bounds on bank liquidity holdings set by the central bank, we are able to define a meaningful measure of a bank's need for liquidity. We call this measure a bank's *liquidity position* and analyze whether it affects the rate a bank pays in the money market. To the extent that a bank's liquidity position affects rates, it is indicative of frictions in the money market. These could be related to e.g. imperfect competition or search.

A cursory glance at the data shows that banks with ample liquidity pay lower rates than do those with less liquidity, see Figure 2.1. At the end of each day, all banks must maintain a positive liquidity position, equivalent to a positive account balance at the central bank. A negative liquidity position indicates that a bank strictly needed a loan to satisfy this requirement. A liquidity position of one corresponds to the maximal amount of liquidity which a bank is permitted to hold at the end of the day. Most borrowing banks typically have much less liquidity; otherwise they would not be borrowing. Figure 2.1 shows that a bank with sufficient liquidity, say a liquidity position greater than 0.4, on average pays 6 to 7 basis points [bps] more than does a bank which requires liquidity. In comparison, the average daily standard deviation of rates is about 15 bps. However, the rate differential could be due to other factors that affect the liquidity position. Perhaps banks are individually liquidity constrained when aggregate liquidity is scarce, in which case the average effect overstates the true effect of a bank's liquidity position on rates. Or perhaps riskier banks choose to hold more liquidity for precautionary reasons, in which case the averages underestimate the effect of liquidity imbalances.

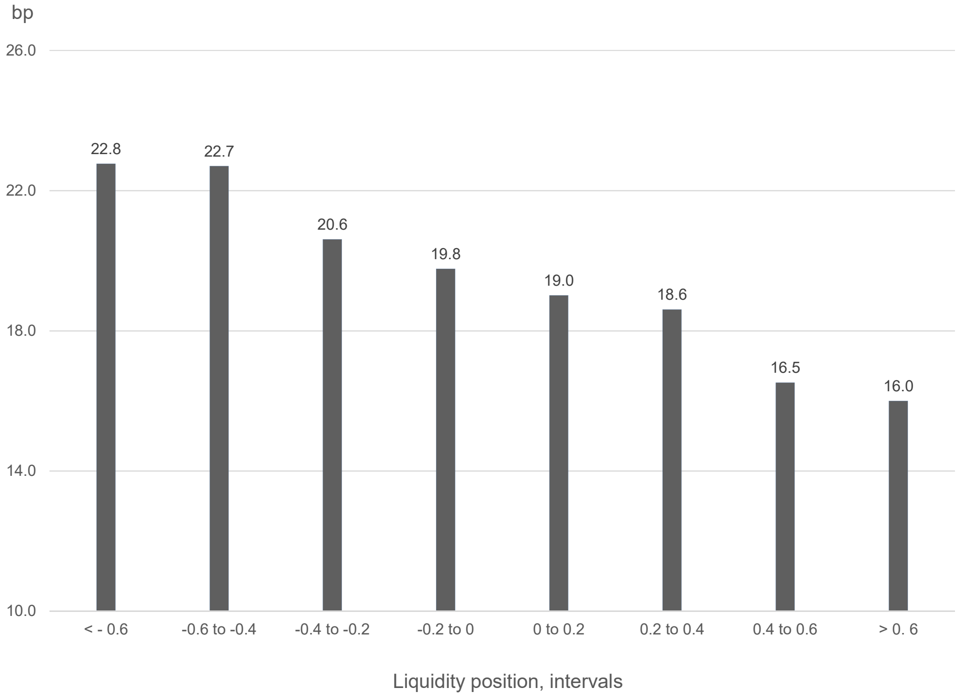

Figure 2.1: Average money market rate less the central bank current account rate, by liquidity position.
The table shows the average interest rate paid by borrowers less the central bank current account rate. Banks are grouped by their liquidity position at the time of borrowing. A bank's liquidity position is defined as its pre-loan current account balance divided by its current account limit, which is a limit on how much liquidity the bank is permitted to hold at the end of the day. The table is based on observations of money market loans (N = 40,103) during the period 2005 to June 2013. Loans between the two largest money market participants have been excluded.

Overall, our analysis indicates that the money market functions well. Banks in need of liquidity pay only marginally higher rates than other banks. On average, a one standard deviation decrease in a bank's liquidity position "costs" less than a single basis point. In some circumstances, though, the liquidity premium is larger. Many money market loans are agreed upon a day in advance of the exchange of liquidity, and so banks have time to find counterparties and need not scramble for liquidity. Since such loans are typically settled early in the day, we look at whether loans for which liquidity is exchanged later in the day are different. These are more likely to reflect a sudden liquidity need due to unexpected payments, and the distribution of liquidity matters more for such loans. The price of liquidity likewise rises when aggregate payment volumes are large. Interbank markets are also characterized by tiering, with most loans involving at least one top tier bank. We find that the liquidity position matters more for rates when a top tier bank is involved in a loan than when two lower tier banks agree on a loan, though the difference is economically small. A possible explanation in our setting is that large banks face tighter limits on their liquidity holdings than small banks relative to their payment volume.

There are notable differences in estimates across subsamples. The liquidity position is insignificant in the pre-crisis period, but significant in the period encompassing the early stages of the financial crisis and culminating in the default of Lehman Brothers. Following Lehman there is a period in which all interbank loans were explicitly covered by a government guarantee, essentially removing credit risk, and in that period the liquidity position is again insignificant. It again becomes significant after the expiration of the government guarantee, suggesting a link between credit risk and the role of bank liquidity.

We address the role of credit risk and its relationship to bank liquidity in some detail. There is no clear, discernible link between regulatory measures of credit risk such as the capital ratio and observed interest rates. One possibility is that banks participating in the money market are of such quality that credit risk is of secondary importance. Another is that credit risk affects the interest rate indirectly via the liquidity position as riskier banks choose to hold more liquidity. In that case, the liquidity position would be a bad control and removing it should alter the estimates of credit risk variables. We do not find any evidence that this is the case. Finally, capital ratios and other ratios based on balance-sheet information may fail to measure time variation in credit risk (we control for time-invariant risk through bank fixed effects).

Endogeneity is a concern if unobserved variation in credit risk affects the liquidity position. We take multiple approaches to deal with this issue. First, we estimate the model interacting bank and month fixed effects. This does not substantially alter our estimates. To control for higher-frequency changes in credit risk, we first apply a differencing strategy. If a bank has a target level of liquidity, the credit risk component of the liquidity position might be removed by identifying a proxy for the target (such as the bank's typical end-of-day liquidity level) and subtracting it from the actual amount of liquidity the bank holds at the end of the day. Implementation of this strategy produces estimates that are quantitatively similar to those obtained by simply including the liquidity position directly. The differenced liquidity position is statistically significant, and the estimates remain economically small, less than a single basis point. An alternative approach is to use an instrument which is correlated with the liquidity position, but not credit risk.

Since many bank payment flows are initiated by customers rather than banks themselves, certain payment flows might have these characteristics, and we find larger parameter estimates using an instrumental variables approach. In subsamples such as the crisis period the cost of having a liquidity position of zero (the required end-of-day position) rather than one (a bank's upper end-of-day limit) exceeds 10 basis points. Instrument validity is a concern, however. Moreover, while this approach yields larger estimates than the other estimates in the paper, it does not alter the conclusion that the money market functions in a relatively efficient manner. It should still be low enough to ensure that banks prefer to use the money market rather than e.g. resorting to borrowing from the central bank against collateral.

Finally, we examine the decision to borrow or lend. Among the key determinants of banks' decision to borrow and lend are past behavior - today's decision is strongly affected by yesterday's - and access to central bank facilities. When banks can borrow from or lend to the central bank, the money market is less active. Unlike in the case of the interest rate regressions, credit risk (or regulatory measures thereof) affect outcomes. As a bank's capital ratio increases, it is more likely to borrow and less likely to lend. The effect is amplified if the liquidity position is excluded from the model, suggesting that safer banks choose to hold less liquidity and then turn to the money market to absorb liquidity shocks. Riskier banks, in contrast, hold more liquidity and provide short-term funds to the better-capitalized banks.

Our main contribution is to address the functioning of the money market in a novel way. Our paper also pertains to the question of whether the distribution of liquidity among agents affects outcomes (Allen and Gale, 2000; Bindseil et al., 2009). The idea of analyzing the effects of the distribution of liquidity on interest rates is not unique to our paper. Fecht et al. (2011), the paper most closely related to ours, address a related issue by looking at data from ECB refinancing auctions. Their focus is therefore on how the distribution of liquidity affects the demand, or willingness-to-pay, for liquidity. Our focus is different, since we are examining a market characterized by competition among lenders. To get a sense of the magnitudes involved, the average difference between the highest and the lowest rate paid on a given day is about 80 basis points in our data set, and these are overnight loans.[1] This compares to a difference of 11.5 bps between the highest and lowest paying banks in the auctions studied by Fecht et al. (2011). Nevertheless, we find that in spite of the large differences in interest rates paid by different banks on a given day, only a negligible part of those differences can be attributed to the distribution of liquidity.

While not the primary object of our analysis, we also touch upon the issue of liquidity hoarding (Acharya and Merrouche, 2013; Acharya and Skeie, 2011; Ashcraft et al., 2011) and the role of credit risk in the money market (Afonso et al., 2011; Heider et al., 2015; Bruche and Suarez, 2010). Specifically, our results indicate that riskier banks choose to hold more liquidity, presumably to avoid having to resort to money market borrowing. We do not directly examine the role of banking relationships (Cocco et al., 2009; Afonso et al., 2013), but do find that the decision to borrow or lend is closely related to whether a bank participated in the market the previous day, likely reflecting rollover behavior.[2] Finally, there are a number of network analyses of the money market (e.g. Bech et al. (2010); Craig and von Peter (2014); Iori et al. (2008)). Our focus is not on network structure, but from these we take the observation that the money market is tiered and may function differently depending on which type of bank is involved in a transaction. Another recent strand of literature attempts to build structural models of the money market (Afonso and Lagos, 2015; Blasques et al., 2014). Such models might prove useful for e.g. studying the effects of alternative central bank policies.

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[1] This average is based on a longer data sample from 2 January 2003 to 17 January 2014.

The money market is also of interest in its own right due to its role in the sharing of liquidity among banks. Indeed, the inability to access liquidity from other banks is a potential cause of bank failures. In addition, the overnight rate (Bernanke and Blinder, 1992; Hamilton, 1996) and stress in the money market (von Hagen and Ho, 2007) are viewed as important indicators of the stance of monetary policy and financial stability. The inability of market participants to access money market funding could adversely affect asset prices (Pedersen and Brunnermeier, 2009). Perhaps most importantly, the risk of being rationed could affect banks' ability or willingness to extend credit to individuals and corporations (Ivashina and Scharfstein, 2010; Puri et al., 2011), with possible consequences for the real economy. Finally, the money market is an interesting example of an over-the-counter market characterized by bargaining and search frictions (Ashcraft and Duffie, 2007).

Our analysis has potential implications for policy. We document that central bank policy and payment flows affect interest rates and money market participation. On days with large payment flows, for example, money market rates are more volatile, and banks in need of liquidity pay more dearly for it. Payment activity, moreover, is affected by policy. The days with greatest payment activity tend to those where the government concentrates certain types of payment, e.g. taxes such as VAT. Likewise, bond issues and interest payments are typically made around the end and beginning of the quarter, and so money market activity is particularly pronounced on such days. This exposes banks to liquidity risk on those days, and banks may find themselves forced to rely on e.g. collateralized borrowing in such times, even though collateral may be in scarce supply.

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[2] In an earlier version of the paper we computed a number of relationship variables and included in our regressions, but found that these variables had little explanatory power. Indeed, their sign often disagreed among measures and across sub-samples, and they were rarely statistically significant.

Finally, some words on data. Our study relies on data from the Danish interbank market. A natural concern is that the results are particular to this market. To mitigate this concern we look at whether patterns in the money market found in other countries are also evident in our data set. Bech and Monnet (2013) document a set of stylized money market facts that hold across six important currencies in the period from 2006-2013, and we observe that these stylized facts are mostly also observed in the Danish market. Moreover, a simple comparison of the money market volumes in Denmark and the US (Afonso and Lagos, 2012) shows a similar time series pattern.[3]

There are, in fact, features of the institutional setup which make the data useful, especially the fact that banks face strong incentives to use the money market due to the institutional setup. Over the period from January 2003 to January 2014, the algorithm used to identify loans finds on average 56 loans per day. This is more than the daily number of loans found in the German market (Bräuning and Fecht, 2012). We also examine a much longer period than other studies of the money market, which have tended to focus solely on the crisis period. Our analysis, which covers the period from April 2005 to June 2013, includes the pre-crisis, crisis, post-crisis and even forays into negative interest rate territory. Also of interest is the fact that we can include sub-period in which interbank loans were guaranteed by the Danish state and a sub-period with negative interest rates.

The rest of the paper is organized as follows. Section 2.2 contains a description of the data and the institutional setting. In Section 2.3 we provide an overview of the activity in the money market during the sample period. Section 2.4 analyzes the determinants of the interest rate. Section 2.5 studies the decision of individual pairs of banks to borrow from and lend to each other, and Section 2.6 considers some event study evidence. Section 2.7 concludes.

2.2. Data and Institutional Setting

The interest rate data is derived from a proprietary transaction-level data set consisting of all payments made by institutions in Kronos, the real-time gross settlement system operated by the Danish central bank. Information on loans between pairs of banks, i.e. loan sizes, rates, counterparties, timing, etc., has been obtained using an algorithm akin to that used by Furfine (1999). The algorithm seeks to identify interbank loans based on payments data. It searches for payments from one bank to another which exceed 1 million in amount and are divisible by 100 thousand, and then pairs these with payments in the opposite direction of the same amount plus a likely interest rate. For instance, if the interest rate is 5%, and there is a payment from Bank A to Bank B of 100 million on day t, then the algorithm will identify an interbank loan if there is a payment of close to 100.0139 (with 0.0139 = 5/360) on date t+1 from Bank B to Bank A.

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[3] To see this, compare Figure 4 in that paper to our figure 2.4.

The interest rate used by the algorithm is obtained as follows: Each day a panel of banks[4] report on their activity in the interbank market, including the rates at which they lend overnight and tomorrow-next. The algorithm first selects the minimum and maximum among the rates reported.[5] It then searches for loans within a band of the minimum reported rate minus 100 bps and the maximum reported rate plus 100 bps. It makes little difference if a narrower band such as e.g. +/- 50 bps is used instead, as the majority of loans fall within a narrow rate band. This method risks both identifying non-loans as loans and failing to identify loans. Arceiro et al. (2014) perform a detailed analysis of the errors associated with using the Furfine (1999) algorithm based on data from TARGET2, the real-time gross settlement payment system used by banks in the Euro Area, and their analysis suggests that the errors involved in the procedure are negligible.[6]

While we have data on loans from January 2003, the data set we analyze runs from April 2005 to the end of June 2013 as quarterly balance sheet data for the banks is only available for that period. In order to have comparable financial information on banks, loans involving foreign counterparties are excluded. We also remove loans between related parties (e.g. banks and associated mortgage lenders). We also exclude failed banks. This is partly motivated by our question of interest. In attempting to determine whether the money market functions, the key issue is whether relatively healthy banks can obtain loans at reasonable rates, not whether any bank can do so. A more practical reason is that the failed banks cannot be correctly identified backwards in time.[7]

In regressions we use as dependent variable the interest on a loan less a reference rate. We discuss the merits of various candidate reference rates at the beginning of Section 2.4. In subsequent analyses, the decision to borrow or lend is the dependent variable. We include three types of controls: (1) bank liquidity variables, (2) bank balance sheet data, and (3) time-series variables. In tables, we report t-statistics based on robust standard errors. However, we have also performed the same inferences using cluster-robust errors and arrive at the same conclusions. For example, in what may be considered the our baseline regression specification (see Table IV, column 1), using cluster-robust standard errors, clustered at the level of borrower-lender pairs, reduces to the t-statistic to 3.07 from 3.32.

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[4] The composition of the panel changes over time. At the time of writing it consists of eight banks, which are among the most active in the money market.

[5] More specifically, it looks at the rates reported on the day in question in the case of overnight rates and the previous business day in the case of the tomorrow-next rates.

[6] A different perspective is provided by Armantier and Copeland (2012) who, based on US (Fedwire) data, argue that the errors can be quite large.

[7] A number of failed banks have been taken over by a government entity that liquidates failed banks. Upon this takeover, the names of the failed banks have been changed backwards in time in the database from which our data is drawn. This implies that the failed banks cannot be distinguished from each other; we can only tell that they were banks which were subsequently taken over.

The liquidity variables are specific to each bank and are observed at a daily frequency. The most important variable in our analysis is the bank's *liquidity position.* Each bank must have a positive current account balance by the end of the day, and it should not have a balance exceeding a limit set by the central bank. The positive account balance is a hard limit whereas the upper limit can in principle be exceeded (as explained more fully in the following section on institutional details). For the same reason, we emphasize the borrower's liquidity position more than that of lenders since a bank in need liquidity faces a more pressing problem than does a bank with too much liquidity.

The liquidity position is computed as follows: For each loan in the sample we first calculate the bank's end-of-day balance minus/plus the loan amount (for the borrower/lender), and then divide this by the bank's current account limit. To illustrate with a simple example, consider a borrower which has borrowed 50 and has an end-of-day current account balance of 70. If the bank's current account limit is 100, the liquidity position is then 0.2 ($= (70 - 50)/100$). This is intended to convey how the bank's end-of-day liquidity would have been *in the absence of the loan.* We make a slight alteration to this definition when analyzing the decision to borrow or lend. In that case we subtract a bank's daily net borrowing from its end-of-day liquidity position.

We also define a broader measure of liquidity, a bank's net position, which is defined as the bank's net claim on the central bank scaled by its current account limit. For example, a bank may have large holdings of certificates-of-deposits, an asset of the bank and a liability of the central bank. These are not immediately available as a means of making payment, but will become current account holdings at the end of a week. In that sense, a large, positive net position is close to immediately available liquidity. Conversely, a negative net position means that banks are net borrowers with the central bank. To borrow they must post collateral, and so obtaining extra liquidity will be costly when the net position is negative.

In order to control for credit risk, or at least examine whether regulatory measures thereof help explain money market rates and market participation, we use quarterly data for each bank's tier 1 and tier 2 capital ratios as well as information on the bank's profits, writedowns, and ratio of deposits to assets. We assign the past quarter's values of these variables to the loan counterparties. One could argue that it is the relative rather than absolute strength of banks that matters in the money market. A bank with a liquidity surplus may be forced to lend, and will require a higher rate when lending to banks that are worse relative to others. To capture this idea, we also define a relative credit risk measure (RCRM). It is computed by first ranking banks based on their core capital ratio, result/weighted-assets, writedowns/core capital and deposit-to-asset ratio (that is, we compute a ranking for each variable) each quarter. We then scale the ranking from 0 to 1 (1 being worst), and finally take a simple average of the scaled rankings.

As controls we include a number of time series variables. One such variable is the aggregate payment volume, and we include not only the current value, but also that of the past and following day. The logic is that if there are many payments, there is also more liquidity which needs to be distributed among banks. Since this distribution may happen with some time lag, we include the value of the previous day's payments; and since banks may borrow or lend in anticipation of tomorrow's payment activity, it is likewise of relevance. We also control for government payment flows. The government's money is held in an account of the central bank, and so a flow to the government represents a drain of liquidity from the banks. Finally, we include the aggregate current account balance of all banks at the beginning of the day and the aggregate net position of the banks. These are again narrow and broad measures of liquidity, only at the aggregate level rather than at the bank-specific level. All payment variables are quoted in billions unless otherwise stated.

We also employ as controls log loan size (in billions) and bank size, defined as the log of total bank assets (in billions). An overview of these descriptive statistics relating to these variables is provided in Table II.

Finally, we include the CDS premium for the Danish government as a measure of aggregate credit risk. These are not particularly informative the earliest part of the sample due to stale CDS-prices.[8]

2.2.1. Institutional Setting

This section provides some background information on the monetary policy framework and the payment system as these affect the functioning of the money market.

The Danish central bank is responsible for maintaining a fixed exchange rate against the euro. In practice, this is done by setting monetary policy interest rates and via interventions in the foreign exchange rates. The key interest rates are the current-account rate, the (7-day) lending rate, and the (7-day) certificate-of-deposit rate. In addition, a so-called "discount rate" akin to federal funds target rate is published. Before May 2007, the lending and certificate-of-deposit rates

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[8] Subsequent to performing these analysis we also attempted using the time series of CDS premium for Danske Bank, the largest Danish bank by assets. While there is a longer series of liquid prices for Danske Bank, including this series does not alter any conclusions. Moreover, the correlation between the two CDS series is about 0.9 so whether one includes one or the other makes little difference in the period where both are liquid.

Table II: Descriptive statistics

Descriptive statistics on the interest on loans less a reference rate (references: CA = rate on current account balances, CD = certificate-of-deposit rate, avg = average daily rate), lender and borrower liquidity variables, bank characteristics such as financial ratios, and time series variables. The data is from the sample period January 2005 to June 2013. The liquidity variable, liquidity position (B=borrower/L=lender), is calculated for each loan, and the net position (B=borrower/L=lender) is calculated daily for each bank. A bank's liquidity position is defined as its pre-loan current account balance divided by its current account limit, which is a limit on how much liquidity the bank is permitted to hold at the end of the day. A bank's net position is calculated similarly, only with the bank's net assets with the central bank replacing the current account balance. The bank characteristics are based on quarterly data. For example, Result/RW-assets refers to the quarterly result scaled by risk-weighted assets. The write-offs represented changes in a bank's account of impaired assets. The other data is based on daily observations. Total payments refer to the total amount of payments in the RTGS-system operated by Danmarks Nationalbank. Gov't payments are the net daily payments made from banks to the government. The aggregate current balance is the sum of all bank's end-of-day balances with the central bank. The aggregate net position is all banks' total claims on the central bank. All data has been obtained from Danmarks Nationalbank.

	Mean	Median	Std. dev.	1st perc.	5th perc.	95th perc.	99th perc.
Loan variables							
$r_{loan} - r_{CA}$ [bps]	15	10	28	-45	-15	60	115
$r_{loan} - r_{CD}$ [bps]	-4	-5	25	-75	-35	35	70
$r_{loan} - r_{avg}$ [bps]	0	0	17	-53	-25	22	54
Loan size [millions]	297	70	654	1	3	1,500	3,500
Liquidity variables							
Liquidity position (B)	0.03	0.01	0.84	-2.31	-1.18	1.23	2.04
Net position (B)	0.88	1.51	14.68	-53.73	-16.68	17	29.02
Liquidity position (L)	0.82	0.52	1.12	0.01	0.02	2.53	5.34
Net position (L)	2.84	4.07	17.55	-97.04	-15.99	19.97	31.02
Bank characteristics							
Assets [billions]	10.8	6.7	35.1	0.6	1.1	602	2,307
Tier I capital ratio [percent]	14.5	13.7	8.1	6	7.7	21.8	42.3
Tier II capital ratio [percent]	16.7	15.7	8.1	9.4	10.3	24.1	44.9
Result/RW-assets [percent]	0.3	0.8	4.3	-14.5	-4.2	2.8	8.3
Write-offs/core capital [percent]	2.8	1.0	14.6	-3.2	-0.9	8.5	32.5
Time series variables							
Total payments [billions]	130.5	125	42.8	59.4	82.5	195.3	269.3
Gov't payments [billions]	0.1	0.2	9	-26.1	-12.9	16.6	29.9
Agg. CA balance [billions]	19.6	12	23.1	3.1	4.8	89.4	100
Agg. net position [billions]	88.8	92.6	70.1	-104.9	-29.5	202.9	228.8

were set on a 14-day basis.

Each day at 3:30 pm banks are required to maintain a positive balance on their current account. Their balance, however, is subject to a cap. The total amount of current account holdings is capped, with each bank assigned an individual limit. Exceeding the individual limit does not necessarily have consequence. The central bank reacts only if the total current account holdings exceed the cap. In that case current account holdings in excess of the individual limits will be converted into certificates of deposit. Since banks can have neither too much nor too little liquidity, the institutional setup gives the banks an incentive to reallocate liquidity from those with a high supply to those with a demand for liquidity. On Fridays, banks can borrow from the central bank against a list of eligible collateral or invest funds in certificates of deposit, but within the week they must source money from other banks (or, to the extent their limit permits it, hold precautionary reserves). The central bank also maintains an account for the government. On days where there are large payments to or from the government, banks are typically permitted to either borrow from the central bank or place funds in certificates of deposits depending on whether liquidity is drained from or added to the system.

The policy regime facing banks changes during the sample. From the beginning of the sample period until June 2009 the lending rate and the certificate of deposit rate were the same. In June 2009, a spread was introduced, strengthening banks' incentives to reallocate funds among themselves in the money market instead of using central bank facilities. For most of the sample period the current account rate is lower than the rate on certificates of deposits. This changed in July 2012 when negative rates were introduced on certificates of deposits while current account rates were kept at zero; at the same time the cap on current account holdings was substantially increased.

Practically all banks maintain their own accounts with the central bank. This contrasts with the system in some countries (e.g. the UK, see Acharya and Merrouche (2013)) where direct membership in the payment system is restricted to a small subset of banks. This structure provides for a richer data set and also lessens concerns that the ultimate beneficiaries of a money market loan might not be the banks identified by the loan algorithm. In most analyses we exclude the two largest banks, which lessens concerns about loans made on behalf of others.

The timing pattern of payments in the Danish payment system is noticeably different from that observed in e.g. the US (Afonso and Lagos, 2012) where most payment activity takes place at the end of the day. In Denmark, most payments are made in the morning, hours before banks are required to have a positive account balance. This pattern is perhaps due to intra-day credit not bearing interest charge in Denmark, though it must be collateralized. This could make early payment an equilibrium as long as collateral is not too costly (Bech and Garratt, 2003). Securities transactions and the previous' days retail payments are settled during the night and are typically paid for using intra-day credit obtained from the central bank. Foreign exchange transactions are settled early in the morning. Some of these payments are known in advance, e.g. securities transactions which are mostly settled on a $T + 2$ or $T + 3$ basis, whereas others, e.g. retail transactions, cannot be perfectly forecast. The upshot is that banks often experience payment shocks in the morning. Most money market loans are settled early in the day, some already when the payment system opens. These can e.g. be overnight loans agreed a day in advance ("tomorrow/next") due to predictable payment flows. The data does not permit one to infer when a loan was agreed.

In the remainder of the paper we report results for subsamples corresponding to different regimes. We divide the time series into five sub-periods. The first is the pre-crisis period, which we define to be the period from April 2005 (the beginning of our sample) to July 2007. The next subsample runs from August 2007 when there were beginning signs of liquidity shortages to 9 October 2008.[9] This end-date is chosen to coincide with the introduction of a government guarantee on 10 October 2008 which specifically covered money market loans. The government guarantee expired at the end of September 2010. We therefore refer to the third subsample as the period of the government guarantee. The fourth subsample runs from October 2010 to 5 July 2012. We refer to this period as the debt crisis period as it coincides with the European sovereign debt crisis. Finally, on 6 July 2012 the Danish central bank introduced negative interest rates and the permitted current account holdings of banks also roughly trebled. We refer to this final period as the negative interest rate regime.

2.3. An Overview of the Money Market

In this section we describe the activity in the Danish money market during the sample period. A more thorough description of the Danish interbank market before, during, and after the financial crisis can be found in Abildgren et al. (2015). Here we mainly consider whether the stylized facts documented in other interbank markets (Bech and Monnet, 2013; Afonso and Lagos, 2012) are also observed in the Danish market.[10] The stylized facts identified by Bech and Monnet (2013) pertain to the expansion of reserves observed in many countries. Such an expansion also took place in Denmark, especially following the European Sovereign Debt Crisis, as the central bank had to print (Danish) currency and purchase foreign currency to maintain a fixed exchange rate. Bech and Monnet find that as reserves expand, 1) overnight rates tend to the central bank rate, 2) market volume decreases, and 3) the volatility of the overnight volume declines.

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[9] It is not clear how to date the start of the crisis. We rely on the information from ECB's timeline of the financial crisis, available at the ECB's website, which dates the beginning of liquidity shortages in August 2007.

[10] In this section we use the full data set, i.e before removing transactions with banks for which we do not have accounting data.

We first look at how the average (value-weighted) money market rate compares to central bank rates over time. Figure 2.2 depicts the central bank rates together with the daily value weighted average rate from our sample.

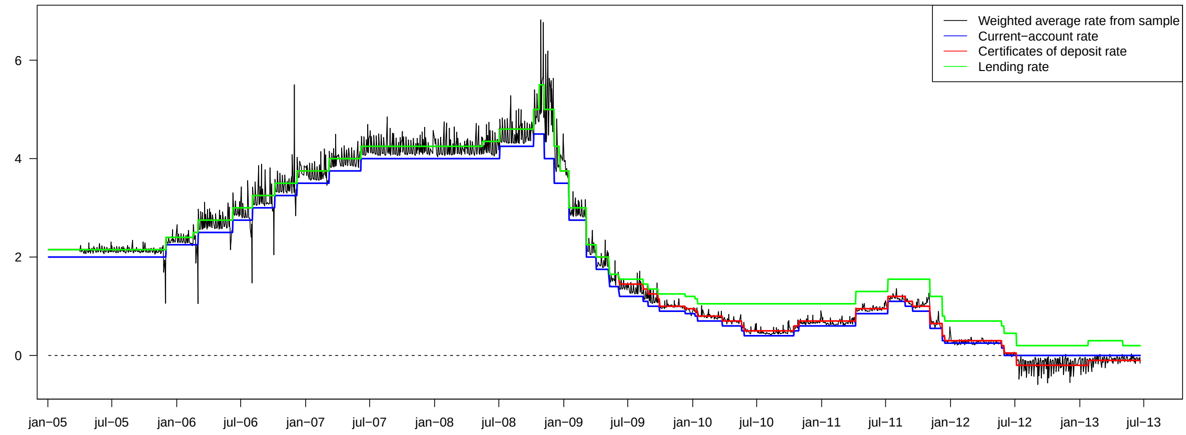


Figure 2.2: Money market versus central bank rates.
This figure shows the evolution of average money market rates (value-weighted) and three central bank rates through the sample period. The current account rate is the rate at which banks' current account balances are remunerated. Prior to May 2007 banks could either borrow at the lending rate or place surplus liquidity in certificates-of-deposits for two weeks. After May 2007 these became weekly operations. The lending and certificate-of-deposit rates were identical until June 2009.

Figure 2.2 shows that the value weighted average interest rate from our sample tracks the central bank rates. In the early parts of our sample the average rate hovers in the middle of the corridor between the current-account rate and the lending rate, with occasional spikes outside the corridor. Most of the spikes above the lending rate occur on Fridays where banks can borrow and lend from the central bank and money market activity is low. From 2010 and until the introduction of negative rates on certificates of deposits the value weighted average rate is at the floor of the corridor and the volatility of the rate decreases, with only few spikes outside the corridor. During the period of negative rates, the value weighted average rate is below the current account rate, and we likewise observe many spikes below the certificates of deposit rate.

The daily intraday standard deviation of the rates is shown in Figure 2.3. Volatility peaks in late 2008 at the height of the financial crisis. Aside from the surge in late 2008, the intraday standard deviation of the rates have been relatively stable over the sample period. There has perhaps not be a decline in volatility as observed in other markets, but this likely is certain special features of the institutional setup. As in other countries, there was also ample liquidity (central bank reserves) in Denmark following the crisis and especially towards the end of our sample, but the requirement that banks cannot have *too much* liquidity may have contributed to continued volatility.

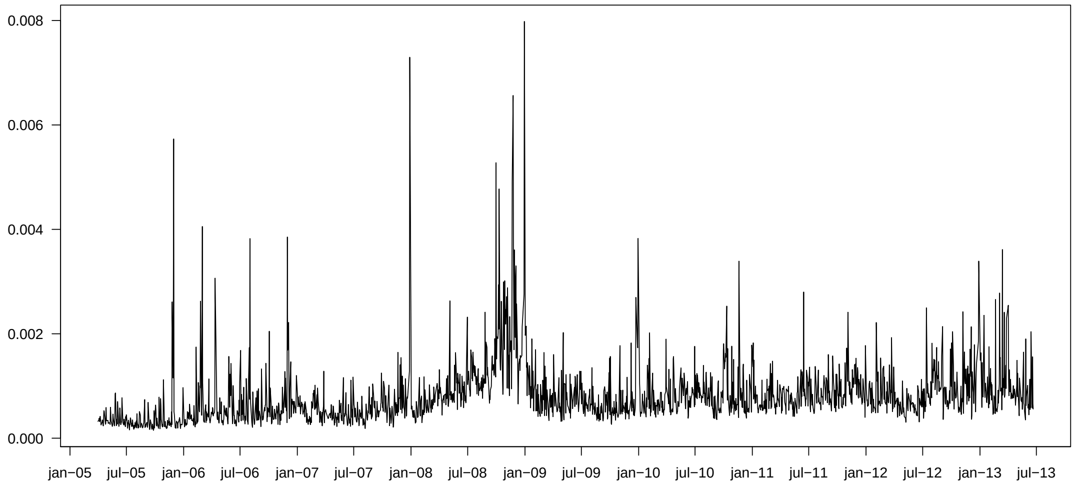


Figure 2.3: Standard deviation of interest rates.
This figure shows the standard deviation of daily interest rates (value-weighted by loan size) during the sample period.

The daily number of loans are given in Figure 2.4. There is a mean of 67 transactions in the pre-crisis period. For the crisis period (August 2007 - 9 October 2008) the average number of transactions is slightly higher at 74. After the onset of the government guarantee, we observe a decline in the daily number of transactions. During the government guarantee period the mean is 57, and during the debt crisis period the figure is 47. The most dramatic decline happens in the period with negative interest rates when the mean number of daily transactions is 23. This can be explained by an increase in the cap on current account holdings which decreased the need for reallocation of liquidity.

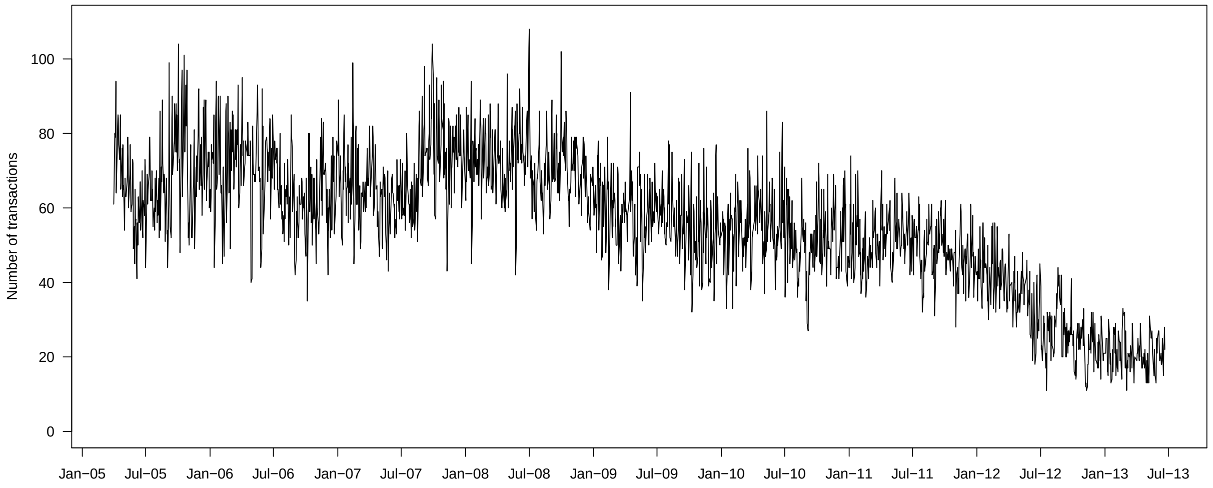


Figure 2.4: The daily number of interbank loans during the sample period.

Looking at the daily number of distinct lenders and borrowers (Figure 2.5) one observes a declining trend through the sample period. The decline in the number of lenders is even greater. The market becomes more tight in the sense that there are the ratio of borrowers to lenders increases. In this sense, the market is least tight during the beginning of 2009 when the number of unique lenders exceeds the number of borrowers, perhaps because lenders can lend with the knowledge that their loans are guaranteed by the state.

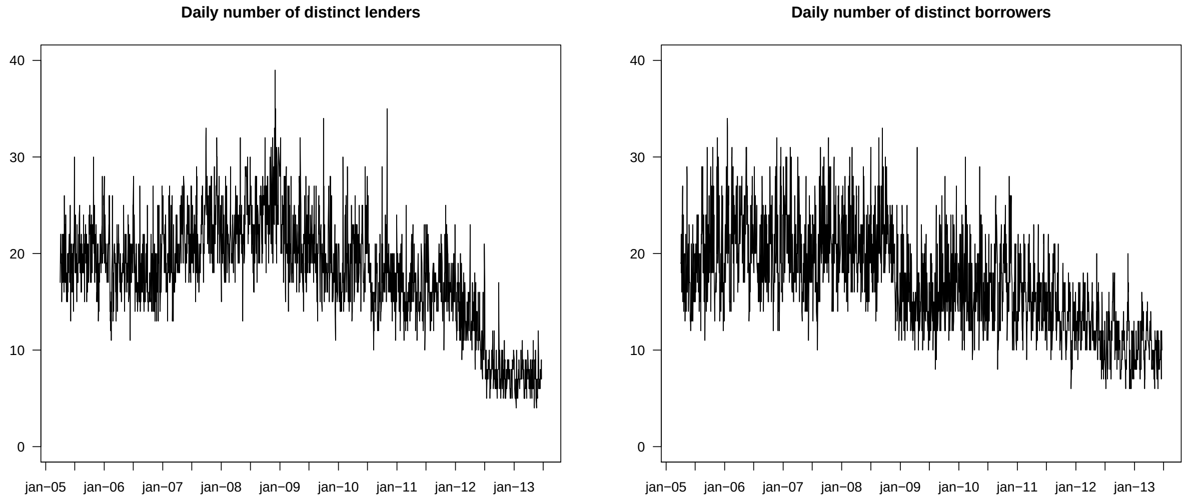


Figure 2.5: Unique lenders and borrowers.
The left panel shows the daily number of unique lenders during the sample period and the right panel shows the daily number of unique borrowers.

Next we look at how many times a bank is lending given that it is lending that particular day. The mean across the entire sample period is 3.21 times. However, the distribution is skewed, with the median between one and two. This finding is similar to what Afonso and Lagos (2012) observe; they likewise find that a few banks lend many times in the US data. Afonso and Lagos (2012) also find a decline in the daily total amount of borrowing. This is in line with a decline in the number of transactions. There is a declining trend in the total amount. However, the trend is less visible in our data. The drop is in the number of transactions, not as much in the total amount.

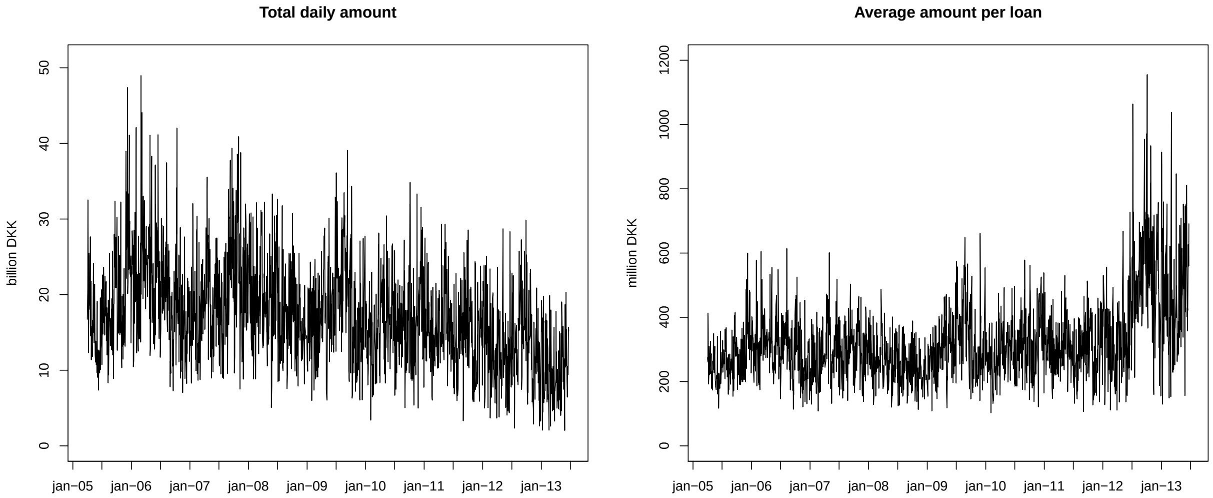
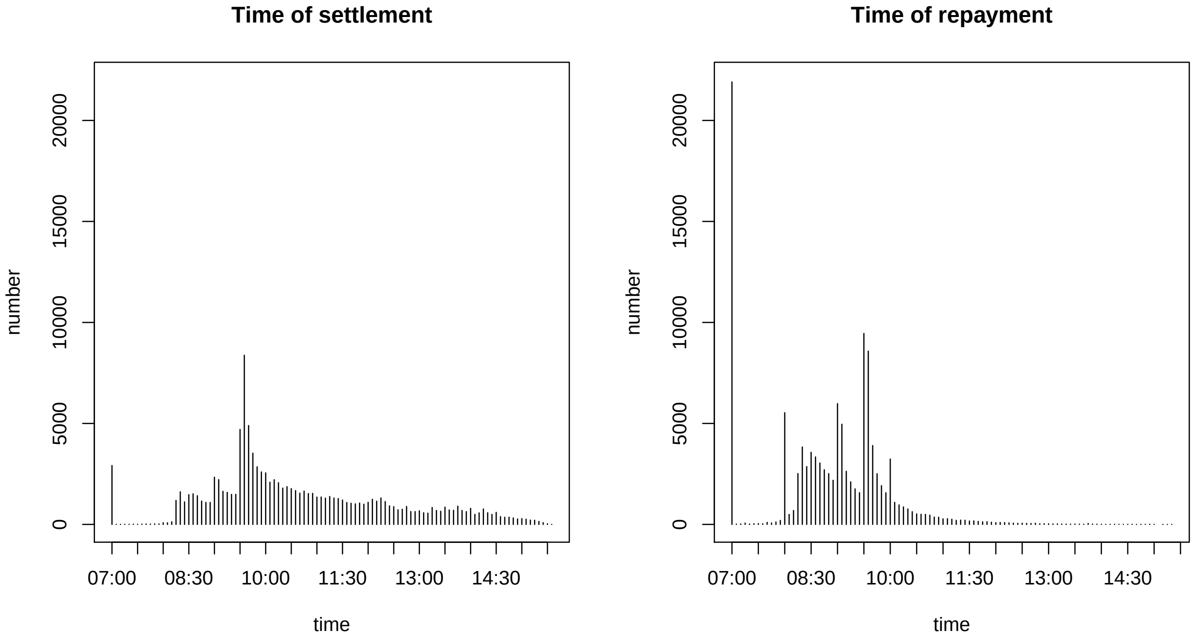


Figure 2.6: Total and average loan amounts.
In the left panel, the daily total amount of overnight loans in our sample and in the right panel the average amount per loan.

Finally, we look at when interbank loans are distributed during the day. Recall, though, that the timing of the payments may not be the same as to the point in time of when the loan has been agreed upon. The "tomorrow/next"-loans are examples of loans which are agreed upon a day in advance such that the transfer time is notably different from the time the loan was agreed upon. We see from Figure 2.7 that the majority of the activity happens during the morning. Especially, most of the loans are repaid at 7.00 AM. This is in contrast to the fed funds market where a significant part of the activity happens end-of-day (Afonso and Lagos, 2012).


Time of settlement

Time of repayment

Figure 2.7: Timing of loan payments.
In the left panel, the distribution over the day of when the loans have been settled. Each bar represents a 5 minutes interval and the height of the bars is the number of transfers within that 5 minutes period. In the right panel we have the distribution over the day of when the loans have been repaid.

2.4. Determinants of Interbank Rates

In this section we examine the determinants of the interest rate agreed upon between pairs of banks. As in other studies (e.g. Afonso et al. (2011); Bräuning and Fecht (2012)) the dependent variable is actually a spread, the rate paid for liquidity less a reference rate. We are interested in whether money markets funds are expensive relative their alternative use. A lender, for example, might choose to keep its money at the central bank, or lend to another bank. A common choice of reference rate is to use the central bank's policy rate; however, we prefer actual rates since an actual rate and not a policy rate represents banks' alternative to exchanging liquidity in the money market. Our preferred option is to use the rate paid on current account deposits since earning that rate is an immediate available alternative to not lending funds on all days.

There are other rates which could be relevant alternatives. On Fridays - and other occasions when the central bank makes this opportunity available - banks can place funds in certificates of deposit. Another alternative to making a particular money market loan would be to lend surplus funds to another bank. The average rate on a particular day can therefore also be used as a reference rate.

Table III shows a comparison of the same baseline regression model with each of the three reference rates, discussed above, as dependent variable. The baseline model includes the set of

Table III: Interest rate regressions - different targets
Cross sectional regressions of loan rates minus reference rates on bank liquidity variables, bank characteristics as well as time-series variables. The columns contain separate regressions for different choices of reference rate, respectively the central bank current account rate, the certificate-of-deposit rate, and the average rate on money market loans on the particular day. Excluded from the sample are loans between the two banks involved in the most money market loans. t-statistics, calculated based on robust standard errors, are in brackets. The dependent variable is quoted in basis points. Details on the computation and measurement units of the independent variables is provided in section 2.2.

	Current account rate		Certificate-of-deposit rate		Avg. daily rate	
Liquidity position (B)	-0.70 (3.97)	-0.55 (3.32)	-0.58 (4.88)	-0.43 (3.56)	-0.51 (7.71)	-0.26 (4.28)
Net position (B)	0.02 (2.77)	0.00 (0.37)	0.02 (2.8)	-0.01 (1.03)	0.02 (7.33)	0.02 (4.27)
Size (B)	-1.85 (25.00)	1.04 (1.36)	-1.83 (28.48)	1.19 (1.35)	-2.01 (57.22)	1.35 (3.04)
Basiscap (B)	8.21 (3.94)	-11.20 (2.32)	7.54 (3.26)	-11.59 (2.39)	11.92 (9.42)	-1.58 (0.65)
Liquidity position (L)	-0.59 (7.33)	-0.47 (5.56)	-0.63 (8.06)	-0.50 (5.98)	-0.42 (9.85)	-0.15 (3.60)
Net position (L)	-0.02 (2.95)	0.02 (2.46)	-0.02 (4.55)	0.01 (1.71)	-0.02 (8.02)	0.00 (1.78)
Size (L)	-0.06 (1.13)	1.46 (2.09)	-0.05 (-0.88)	1.68 (1.96)	0.23 (7.99)	0.10 (0.22)
Basiscap (L)	-23.95 (9.10)	11.14 (2.55)	-22.86 (8.28)	12.2 (2.51)	-34.19 (22.62)	5.56 (2.27)
Loan size	-0.86 (7.43)	-0.14 (1.14)	-0.87 (8.22)	-0.16 (1.35)	-0.39 (6.76)	0.21 (3.64)
Agg. CA balance	-0.45 (14.78)	-0.44 (15.33)	-0.39 (17.64)	-0.38 (18.10)	0.03 (2.74)	0.02 (2.13)
Agg. net position	-0.18 (17.01)	-0.17 (16.48)	-0.12 (14.54)	-0.11 (13.89)	-0.01 (2.00)	0.00 (0.55)
Friday	10.93 (38.84)	10.67 (38.46)	10.81 (39.65)	10.54 (39.55)	0.31 (2.08)	0.46 (3.44)
Gov't payment flow	0.08 (4.48)	0.09 (4.86)	0.12 (10.24)	0.13 (11.05)	-0.02 (3.64)	-0.02 (3.44)
Total payments (t)	0.04 (13.82)	0.04 (13.19)	0.04 (15.5)	0.04 (14.92)	0.01 (7.00)	0.01 (6.93)
Total payments (t-1)	0.02 (9.31)	0.02 (9.05)	0.02 (8.88)	0.02 (8.67)	0.00 (0.97)	0.00 (0.75)
Total payments (t+1)	-0.01 (2.44)	-0.01 (3.25)	0.00 (1.36)	0.00 (0.07)	0.01 (5.53)	0.01 (4.19)
CDS (gov't)	0.05 (1.93)	0.06 (2.06)	-0.13 (7.35)	-0.12 (7.36)	-0.04 (3.93)	-0.04 (4.36)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Bank FE	No	Yes	No	Yes	No	Yes
R^2	0.46	0.50	0.19	0.25	0.20	0.37
N	40103					

controls discussed in Section 2.2. The results are qualitatively similar across choices of dependent variable. The variable of main interest, the borrower liquidity position, has the same sign and is statistically significant in each case. It appears that we are better able, in terms of R^2, to explain the variation in the dependent variable when we use the current account rather than the certificate of deposit rate. It would not be fair to make a similar comparison with the case of the average market rate since we discard much of the information available in the time series variables when subtracting an average.

Another finding is that controlling for borrower and lender fixed effects mainly affects the results for bank-specific variables such as the capital ratio and bank size. As an example, the parameter estimate for the capital ratio decreases when fixed effects are included, meaning that with fixed effects there is more evidence that better capitalized banks pay lower rates, though the result in insignificant here. A possible explanation is that unobserved factors related to a bank's quality simultaneously permits it to hold less equity and borrow at lower rates.

Our primary interest is in the liquidity position variables, especially the borrower liquidity position. While the liquidity positions are statistically significant, the parameter estimates are small from an economic perspective. Using our preferred reference rate, the parameter estimate is -0.55. This implies that covering a one standard deviation decrease in the liquidity position would cost only an additional 0.46 basis points. Such a figure suggests that the money market functions well in general. With the cost of finding liquidity being low, banks have an incentive to keep their current account balances low and use money market transactions to absorb liquidity shocks.

The signs of the other regression coefficients are largely as expected. Borrowers with less liquidity pay higher rates. Larger banks pay substantially lower rates when fixed effects are not included, but the effect vanishes once included. Curiously, banks with more equity (tier 2 capital) appear to be paying higher rates when fixed effects are accounted for.

The time series variables likewise behave in accordance with expectations. When aggregate liquidity is ample, whether in the form of immediately available liquidity (current account balances) or other assets with the central bank (net position), money market rates are lower. Rates are higher when liquidity is drained from the system due to the government receiving money from banks. On Fridays, or other days where lenders can place their money with a central bank for a week at a higher rate, they also receive a rate that is about 11 basis points higher. In comparison, the certificate of deposit rate has on average been about 15 basis points above the current account rate in the sample period. As expected, rates are also higher when current or past payment activity is large, though the opposite is true in the case of tomorrow's payment activity. If the time fixed effects are excluded, the regression coefficients barely change, but the overall fit declines somewhat. For example, without time fixed effects the R^2 in the third column of Table III would drop to 0.35 from 0.50, but the estimate of the liquidity position would be virtually unchanged, decreasing slightly from -0.55 to -0.58.

In the above we have excluded the two largest banks. Network analyses in the money market emphasize the presence of different tiers of banks, and the Danish market is no exception. Two banks in particular play a vital role in the distribution of liquidity. Of the 75,722 loans we analyze, only 25,738 involve neither one of the banks (either directly or as correspondent for some other financial institution). We generally exclude these banks from regressions, one reason being that these banks function as correspondents for other banks which means that many of the loans we observe between these banks really involve other banks for which we do not have data. In Table IV, we show results with these banks included.

Table IV shows how the parameter estimates vary for different subsets of banks. One might expect that the largest banks, due to greater diversification and better ability to forecast liquidity

Table IV: Interest rate regressions - tiering

Cross sectional regressions of loan rates minus reference rates on bank liquidity variables and characteristics as well as time-series variables. The columns represent separate regressions depending on the subsample: (1) includes all loans except loans between the largest two banks, (2) includes only loans to which neither of the largest two banks is a counterparty, (3) includes loans where one the two largest banks is a borrower, and (4) includes loans where one of the two largest banks is a lender. t-statistics are in brackets, and are calculated using robust standard errors. The dependent variable is quoted in basis points. For details on the computation and measurement units of the independent variables, see section 2.2. Bank and month fixed effects are included in the regressions.

Reference rate	(1)	(2)	(3)	(4)
Liquidity position (B)	-0.55 (3.32)	-0.47 (2.86)	-2.10 (3.30)	0.37 (0.66)
Net position (B)	-0.00 (0.37)	0.00 (0.64)	-0.02 (0.27)	-0.05 (1.33)
Size (B)	1.04 (1.37)	2.59 (2.73)	-3.67 (0.76)	0.28 (0.17)
Basiscap (B)	-11.20 (2.33)	-6.64 (0.97)	35.59 (1.35)	-11.83 (1.64)
Liquidity position (L)	-0.47 (5.57)	-0.57 (6.02)	-0.31 (1.13)	3.01 (6.99)
Net position (L)	0.02 (2.46)	0.01 (2.17)	0.04 (1.25)	0.01 (0.19)
Size (L)	1.46 (2.09)	2.83 (3.59)	4.91 (2.33)	0.45 (0.15)
Basiscap (L)	11.14 (2.55)	7.68 (1.27)	1.53 (0.16)	15.92 (0.98)
Loan size	-0.14 (1.15)	0.16 (0.97)	-1.15 (3.45)	0.16 (0.49)
Agg. CA balance	-0.44 (15.37)	-0.33 (8.93)	-0.92 (8.74)	-0.63 (11.65)
Agg. net position	-0.17 (16.53)	-0.18 (14.57)	-0.19 (5.79)	-0.14 (6.66)
Friday	10.67 (38.55)	11.37 (34.69)	11.37 (12.96)	7.39 (12.28)
Gov't payment flow	0.09 (4.87)	0.09 (4.30)	-0.16 (3.15)	0.23 (6.28)
Total payments (t)	0.04 (13.22)	0.04 (10.26)	0.07 (7.76)	0.04 (6.01)
Total payments (t-1)	0.02 (9.07)	0.02 (7.56)	0.01 (1.63)	0.02 (5.53)
Total payments (t+1)	-0.01 (3.26)	-0.00 (1.15)	-0.07 (6.47)	-0.01 (1.23)
CDS (gov't)	0.06 (2.07)	0.06 (1.97)	0.12 (1.87)	-0.04 (0.55)
R^2	0.50	0.52	0.49	0.53
N	40103	25738	4395	9970

flows, are less affected by liquidity shocks. In that case the liquidity position should matter more when small banks are involved. Yet, if one excludes all loans between the two largest banks (column 1), the parameter estimate for the borrower liquidity position drops. It falls even further when the sample is restricted to loans between smaller banks (column 2).

Another possibility is that results are asymmetric, i.e. that large banks pay low rates as borrowers, but charge high rates as lenders. Large banks may be able to extract rents due to an informational advantage. Perhaps they are better at forecasting liquidity flows than smaller banks and can therefore infer the liquidity positions of other banks and charge accordingly. The results suggest otherwise, however. The large banks pay more when in need of liquidity (column 3).

A possible explanation of this phenomenon is that large banks actually face tighter liquidity constraints than small banks. While their limits on their current account holdings exceed those of small banks, the limits are substantially smaller when measured against magnitude of payments handled by the large banks.[11] When the large banks are lenders, a different picture emerges. The liquidity position of borrowers no longer matters, suggesting that the large banks are not exploiting superior knowledge about the liquidity position of other banks. However, when the large banks themselves have ample liquidity, they charge higher, not lower rates. This could be because they account for such a large share of the market that they know that if they have ample liquidity, potential counterparties must be in the opposite position.

There are further issues involved in estimating the consequences of banks having a particular liquidity position. One concern is that some loans are agreed upon a day in advance (so-called "tomorrow/next"-loans), while others are agreed upon on the day of the loan. We are unable to identify which are which, but there is a market convention that tomorrow/next loans should be settled before noon. We therefore introduce a variable which indicates whether a loan has been settled after noon. Our expectation is that the liquidity position matters more for such loans. It also seems likely that the liquidity position matters more on days with large payment flows where there is more liquidity to be exchanged and therefore e.g. greater search costs involved. Likewise, if aggregate liquidity is scarce - the aggregate current account balance or the aggregate net position is low - the liquidity position may matter more.

These predictions are borne out by the data. If we repeat the regressions from earlier, but include interaction terms between the borrower's liquidity position and these variables, the results are significant. The parameters of interest are reported in Table V.

To put the estimates in perspective, one must consider the amount of variation in the variables

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[11] This has been suggested to us by a former liquidity manager at a large bank.

Table V: Liquidity position - interactions
This table provides regression estimates of the borrower's liquidity position and interactions of other variables with the liquidity position. The set of other controls (not shown) is the same as in the regressions reported in Table III, i.e. controls related to borrower and lender characteristics, payment and time series variables, and time and bank fixed effects. Excluded from the sample are loans between the two banks involved in the most money market loans. t-statistics based on robust standard errors are in parentheses. The sample size is N = 40,103.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Liquidity position (B)	-0.55 (3.32)	-0.40 (2.26)	0.35 (0.81)	-1.27 (5.36)	-1.47 (3.83)	-1.33 (3.38)	-0.55 (0.99)
. * post-noon (1/0)		-0.59 (2.12)					-0.44 (1.72)
. * total payments (t) [100 bn]			-0.69 (2.03)				-0.62 (1.83)
. * agg. CA balances [10 bn]				0.51 (4.32)			0.28 (2.18)
. * agg. Net Position [10 bn]					0.11 (3.39)		0.10 (2.66)
. * Tier 2 capital [%]						0.06 (2.44)	-0.03 (2.80)

with which the liquidity position is being interacted. For instance, in the sample period the aggregate net position changes from less than -100 bn to more than 200 bn, implying a variation in the borrower liquidity position estimate of about 3 basis points throughout the sample period. We also observe that the liquidity effect is stronger for loans settled later in the day, indicating, presumably, more urgency on the part of borrowers. Moreover, when aggregate liquidity is greater, whether in the form of immediate liquidity (current account balances) or other central bank assets (the net position), the liquidity effect is weaker. These findings highlight that liquidity premia are higher when liquidity is needed the most. Nevertheless, the economic magnitudes remain small. It does not seem too costly, though, as the cost will rarely exceed a few basis points.

2.4.1. Credit Risk and Liquidity

In the preceding section only a single variable directly related to credit risk, the tier 2 capital ratio, was included as an explanatory variable. In this section we examine the role of credit risk in more detail. Initially, we consider the inclusion of other credit risk measures. The upshot of that analysis is that there is no strong evidence of a clear, direct relationship between money market rates and credit risk measures based on bank balance sheet information.

One possibility is that credit risk simply does not affect money market rates. Perhaps banks choose which banks they are willing to lend to but, once a bank is considered safe enough to be a counterparty, there is no further price adjustment. Another possibility is that credit risk does matter, albeit in a way not captured by our regression. There might be an indirect relationship if riskier banks choose to hold more liquidity than less risky banks. Or maybe our measures of credit risk, imperfect as they are, fail to measure credit risk.

To motivate these concerns further, suppose that the interest rate on money market loans is determined by the following stylized model with both direct and indirect effects of credit risk, the indirect effect being via the liquidity position:

$$\begin{aligned} r_{i,t} &= r_f + \alpha_i + \beta_1 \times Liquidity_{i,t} + \beta_2 \times Risk_{i,t} + \epsilon_{i,t} \\ Liquidity_{i,t} &= Liquidity^{EOD}_{i,t} - Borrowing_{i,t} \\ Liquidity^{EOD}_{i,t} &= Liquidity^{EOD}_{i,t-1} + Borrowing_{i,t} + Liquidity^{Shock}_{i,t} \\ Borrowing_{i,t} &= \rho \times (Target_{i,t} - Liquidity^{EOD}_{i,t-1} - Liquidity^{Shock}_{i,t}) \\ Target_{i,t} &= \theta_0 + \theta_1 * Risk_{i,t} \end{aligned}$$

The stylized model says that the interest rate paid by a bank on a given day is determined by bank-specific factors, the bank's liquidity position, and bank credit risk. The second and third equations are identities. The first links a bank's liquidity position to its end-of-day-liquidity and the net borrowing undertaken by the bank. The second links the end-of-day position to the previous day's end-of-day position and liquidity flows. The two final equations are behavioral equations, the first expressing the amount of borrowing as a function of deviations between actual and target liquidity, the second saying that riskier banks prefer to hold more liquidity.

In the case of $\rho = 1$, implying that banks fully offset liquidity shocks by borrowing, the expression for the liquidity position is $Liquidity_{i,t} = Target_{i,t} - \theta_1 \times \Delta Risk_{i,t} + Liquidity^{Shock}_{i,t}$. If $\rho < 1$, the expression still includes the current liquidity shock, but also a geometrically weighted sum of past liquidity targets and shocks.

The above points to some of the econometric difficulties when regressing loan rates - and suggests solutions. If we have a variable that actually measures credit risk, we will be estimating β_1, the liquidity position coefficient, correctly. We will, however, be overestimating the effect of credit risk on loan rates. When $\rho = 1$, for instance, the actual credit risk effect is $\beta_2 + \beta_1 * \theta_1$, and we expect a negative value of β_1. In other words, if we are interested in credit risk, the liquidity position is a bad control, and we would do better by excluding it from our regressions.

A different econometric issue appears if our problem is a failure to measure the credit risk of banks. In that case, credit risk is part of the error term and correlated with the liquidity position. We are thus faced with an endogeneity issue, suggesting that we search a valid instrument for the liquidity position. To be sure, the above model is intended only to illustrate potential econometric difficulties, and there is no suggestion of it being a an accurate representation of how rates are set. Indeed, minor variations to the model could change the interpretation of the results: If the interest rate were to depend directly on the liquidity shock, say, and one estimated the model using liquidity position and credit risk as covariates, β_1 would still be properly estimates, but the credit risk effect would be underestimated.

We first address the issue of bad controls. Table VI reports the regression results for the full sample and each of the five subsamples, we examine. It includes estimates of the liquidity position

Table VI: Credit risk and the liquidity position
This table shows regression estimates of the liquidity position as well as credit risk measures based on balance sheet data. Estimates are reported for five subsamples. They relate to the borrower in a transaction, not the lender. The set of other controls includes the same payment and time series variables as in Table III. Time and bank fixed effects are also included. In the base specification the only credit risk variable included is the tier 2 capital ratio; the set of full controls include the tier 2 capital ratio, write-offs, the deposit-to-assets-ratio and the relative credit risk measure (RCRM). t-statistics based on robust standard errors are in parentheses.

	Liq. controls	Pre-crisis	Crisis	Gov't guarantee	Debt crisis	Neg. interest rates
Liquidity Position (base spec.)	-	-0.06 (0.21)	-2.30 (5.04)	-0.31 (1.43)	-0.30 (1.98)	-0.41 (0.53)
Liquidity Position (full controls)	-	-0.07 (0.24)	-2.27 (4.90)	-0.30 (1.40)	-0.30 (2.00)	-0.41 (0.52)
Tier 1 capital ratio	Yes	28.28 (2.18)	-24.39 (1.25)	23.92 (1.49)	-29.21 (4.41)	2.18 (0.41)
	No	28.09 (2.16)	-24.03 (1.23)	27.09 (1.69)	-28.19 (4.29)	-3.52 (0.15)
Tier 2 capital ratio	Yes	36.12 (3.32)	-13.26 (0.89)	3.06 (0.22)	-30.50 (4.77)	23.93 (1.10)
	No	35.67 (3.27)	-11.95 (0.81)	5.37 (0.38)	-30.78 (4.82)	12.21 (0.59)
Write-offs	Yes	-30.82 (1.53)	-22.66 (0.52)	-5.25 (1.96)	-7.33 (1.93)	6.31 (0.40)
	No	-31.96 (1.53)	-16.83 (0.39)	-5.19 (1.93)	-7.22 (1.90)	20.31 (1.31)
Result	Yes	-7.48 (0.31)	184.53 (3.19)	34.40 (1.49)	14.57 (0.61)	48.30 (1.33)
	No	-7.07 (0.29)	181.95 (3.16)	37.03 (1.62)	18.71 (0.79)	5.46 (0.16)
RCRM	Yes	-2.51 (1.13)	-9.38 (2.06)	-2.12 (0.82)	0.58 (0.49)	0.41 (0.12)
	No	-2.64 (1.19)	-9.40 (2.06)	-2.56 (1.00)	0.21 (0.18)	2.74 (0.81)
N		11,800	6,408	11,534	8,299	2,062

with just the tier 2 capital ratio as a control and with a broader set of credit risk controls and parameter estimates for each of the credit risk controls with and without the liquidity controls.

The liquidity position estimates (here we focus on the borrower) are of the expected sign, though only statistically significant in the period encompassing the crisis and the period during which the European debt crisis took place. It does not matter pre-crisis, in the period of government guarantees, or in the negative interest rate regime when liquidity was generally ample. Moreover, the estimates do not depend on whether more credit risk controls are included. There is no evidence of a problem of bad controls. The parameter estimates for the credit controls likewise do not depend on whether liquidity controls are included.

Table VI shows that the parameter estimates for the credit risk are sometimes insignificant, inconsistent over time, and in some cases of unexpected sign. For instance, the results indicate that banks with more write-offs and worse results pay lower rates. Moreover, even the variables are statistically significant, their economic significance is limited. As an example, consider the core capital ratio in the fourth subperiod from October 2010 to early July 2012 where we find a parameter estimate of -29.21. In economic terms, this means that a bank should experience a decrease in money market rates of 0.3 basis points for a percentage point increase in the core capital ratio.

If we are faced with an endogeneity problem rather than a problem of bad controls, more possible solutions present themselves. One solution might be to control for credit risk at a higher frequency, not by using specific measures of credit risk, but by taking interactions of time (month)

Table VII: Liquidity position estimates with interactions of fixed effects
This table shows regression estimate of the borrower's liquidity position when controls, bank fixed effects, time effects and interactions of bank and time fixed effects are included in the regression. Estimates are reported for the full sample as well as five subsamples. t-statistics based on robust standard errors are in parentheses.

	Full sample	Pre-crisis	Crisis	Gov't guarantee	Debt crisis	Neg. interest rates
Liquidity Position	-0.37 (3.01)	-0.06 (0.27)	-1.29 (3.52)	-0.13 (0.39)	-0.55 (3.38)	0.41 (0.47)
N	40,103	11,800	6,408	11,534	8,299	2,062

and bank fixed effects. This should be sufficient to the extent that we are not concerned by even higher frequency variation in unobserved credit risk. This is a real concern, however, and we attempt to address it in two ways. The first is to identify a direct measure of the liquidity shock and include that rather than the liquidity position, while the second is to identify a suitable instrument (or instruments) for the liquidity position.

Table VII shows the estimates of the liquidity position effect when interactions of time and bank fixed effects are included. We observe the same pattern across subsamples as in Table VI; however, the estimated magnitudes are even smaller, indicating that banks in need of liquidity do not pay substantial liquidity premia.

In order to identify a liquidity shock measure, a natural choice seems to be to subtract the target liquidity position of the bank from its liquidity position since that can be thought of as a shortfall relative to target. A bank's target liquidity is not observable, however. As a proxy for the bank's target we use the bank's actual end-of-day-liquidity on the previous day (and examine averages using more days as well). Incidentally, the difference between the liquidity position and the end-of-day position of the previous day equals the liquidity shock in the stylized model discussed at the beginning of the section, though it presumably would not in a more realistic model of the money market. In the stylized model, for instance, the liquidity shock is identical to the net payment activity, much of which certainly is predictable and therefore cannot be thought of as a shock, and banks might obtain longer-term (e.g. central bank) loans to offset predictable outflows. The same sort of behavior might lead the actual liquidity position to deviate from the target in a systematic fashion.

Using this differencing approach does not result in markedly different estimates. If we use the past day's end-of-day liquidity as a measure of target liquidity, the resulting parameter estimates for the borrower liquidity position and the lender liquidity position are -0.31 ($t = 2.47$), close to the estimate found when including fixed effect interactions, and -0.17 ($t = 2.43$) respectively. These estimates are based on the same specification as in Table IV, column 1. The estimates are less negative than the estimates based on the liquidity position.

If we use the average of the past five days as a measure of the target instead, the estimates are

Table VIII: Liquidity and interest rates The table shows the interest rate differential between the loan rate and the central bank current account rate as a function of borrowers' and lenders' liquidity position. Results are reported for the full sample, September 2008, and the period with negative interest rates respectively. The figures are based on all loans except those between the two most active money market participants.

	Full sample		September 2008		Neg. interest rates	
Rate paid - CA rate (BP)	Lender: Liq. pos. > 1	Lender: Liq. pos. < 1	Lender: Liq. pos. > 1	Lender: Liq. pos. < 1	Lender: Liq. pos. > 1	Lender: Liq. pos. < 1
Borrower: Liq. pos. > 0	12.2	20.7	39.4	43.4	-11.5	2.1
Borrower: Liq. pos. < 0	16.9	23.5	37.4	40.0	-6.5	5.1

close to the earlier estimates. Using the liquidity shock, we obtain an estimate of -0.57 ($t = 3.73$) for the borrower compared to -0.55 when using the liquidity position. For the lender, the corresponding estimates are -0.44 ($t = 5.26$) versus -0.47. Extending the averages based on which the liquidity shocks are calculated to e.g. 10 or 20 days does not materially change the figures.

A second solution to the endogeneity problem is to use an instrument for the liquidity position. A possibility is that our credit risk proxies, based on accounting data as they are, simply are not good measures of credit risk. To provide some further motivation we note that there is some simple, but suggestive evidence in the data of a link between credit risk and banks' liquidity holdings. Specifically, there are indications that riskier banks do choose to hold more liquidity at the peak of the crisis. This can be seen by comparing the rates paid by banks as a function of their liquidity position. In general, we would expect that banks with more liquidity to pay lower rates when they borrow and to require lower rates when they lend.

A means of illustrating this is to compare the rates paid with borrowers for which the liquidity position variable is either positive or negative and for lenders for which it is either larger or smaller than one. For a borrower, a negative value of the variable means that the borrower would have had a negative end-of-day current account balance if the borrower had not obtained the loan. For a lender, a value of the variable above one indicates that the lender would have exceeded its limit if it had not. In table VIII we divide the loans into four categories based on borrowers' and lenders' liquidity position and compare the interest rates agreed upon by borrowers and loans.

In the full sample the pattern is as expected: Borrowers and lenders with ample liquidity pay and receive lower rates. That pattern is not reproduced in the September 2008. While all rates are higher than in the full sample, the more interesting fact is that borrowers who are in less need of liquidity actually face the highest rates. This pattern is consistent with liquidity hoarding, since the worst banks may also be those who for precautionary reasons choose to hold the most liquidity.

Interestingly, all banks except the very smallest do borrow occasionally, even at the peak of the crisis. In the data set on which we perform our regressions, the average number of distinct borrowers per month in the period from April 2005 to December 2007 is 27.2. In July, August, and September of 2008 there are 30, 27, and 28 distinct borrowers respectively.

While this pattern is curious, it is not entirely unique to September 2008. In the pre-crisis period, when the liquidity position of banks appeared to matter little, it is common to find no discernible relation between borrowers' need of liquidity and the rates they pay. In the period after the expiration of the government guarantee (that ran from October 2008 to October 2010), however, such a pattern is rarely observed. On average, borrowers with a negative liquidity position pay 4.3 bps more than those with a positive liquidity position in that period. In only 3 out of 33 months do we observe the opposite sign. This occurs in December 2010 (-1.6 bps), December 2012 (-0.1 bps), and June 2012 (-0.3 bps). This compares to a difference -3.0 bps in September 2008.

Since it might be of interest, we also include results for the period of negative interest. The qualitative pattern is the same as in the sample as a whole, but we also observe that lenders are willing to accept lower rates than they would earn by simply keeping money in their account. This could be because they fear exceeding their current account limit and having their current account holdings converted to certificates-of-deposits which earn even lower rates.

When looking for instruments we are hoping to find variables which themselves are irrelevant to the determination of money market rates when other factors have been controlled for, which are correlated with the liquidity position of banks and uncorrelated with credit risk. Certain payment flows seem promising candidates. For example, daily variation in retail payments (such as consumers' card payments at retail stores) is outside the control of the bank and presumably unrelated to bank credit risk, at least as long as that consumers do not withdraw funds in a bank run.[12] Unfortunately, retail payments constitute a negligible part of total payments and turns out to be a weak instrument. The F-statistic from the first-stage regression of the borrower liquidity position on the instrument is 4.0, while a rule-of-thumb suggests that a value in excess of 10 is required. The resulting estimate of borrower liquidity position coefficient is about -8.7, but the figure is not remotely significant ($t = 0.08$).

An alternative is to use a broader set of payments such as payments resulting from securities trading. We therefore attempt to use total net payments (excluding interbank payments) as an instrument. Total net payments is certainly more strongly correlated with the liquidity position than net retail payments, but its validity as an instrument, however, is also more questionable. For example, banks both handle securities transaction on behalf of customers and for themselves. One could imagine a liquidity constrained bank selling securities to raise cash, creating a link between credit risk and the instrument.

To mitigate concerns about instrument validity, we have collected data on daily total net

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[12] In fairness, there could be sources of correlation between consumer payment behavior and bank risk. As an example, a regional bank might be located in a region in a decline, which might be associated with both risk to the bank and particular payment patterns. However, one might correct for trends in net retail payments, if any.

Table IX: Failed banks and money flows

For 11 banks which failed in the period 2007-2013, the table reports average standardized liquidity flows and the fraction of days with negative standardized flows in the calendar month preceding the failure of each bank. The standardized liquidity flows are calculated for each bank and day in the month by taking a bank's daily net payment, subtracting the average daily net payment of the bank over the period 2005-failure, and then dividing by the average absolute value of the daily net payment of the bank over the period 2005-failure.

Bank	1	2	3	4	5	6	7	8	9	10	11	Total
Avg. liquidity flow	-0.96	-0.09	0.31	0.19	0.39	0.41	0.84	-0.06	0.13	-0.89	0.07	0.01
Outflow days (fraction)	0.67	0.72	0.56	0.37	0.29	0.25	0.50	0.48	0.36	0.59	0.65	0.50

payments for 11 failed banks for the calendar month preceding the bank failure. We calculate the daily total net payments for each bank and day in the month, subtract the average daily net payment (over the period 2005 until the end of the bank's life) and then scale by the average absolute value (over the same period). This produces a standardized score and helps us understand whether these banks, which were arguably in difficulties, experience unusual payment flows such as outflows due to customers taking their business elsewhere. No such pattern is observed; the scores seem quite random, see Table IX. Only on half of all days, 104 of 210, do these banks experience larger than average outflows.

Unlike retail payments, total net payments turn out to be a strong instrument for borrowers' and lenders' liquidity positions. In Table X, we include the output of the first-stage regressions since they are informative not only about the strength of our instruments, but also show how other covariates relate to the liquidity position. As an example, we observe a link between the capital ratio and the liquidity position, especially of lenders. It appears that banks with more capital are willing to lend from a position of holding less liquidity than banks with less capital. We examine this further in the next section.

The estimates of main interest are those of the liquidity positions. The estimate for the borrower liquidity position is -6.00, implying that a borrower with a liquidity position of 1 would pay fully 6 basis points less than a borrower with a liquidity position of 0. Another way of putting the figures in perspective is to note that a one standard deviation decrease in the liquidity position "costs" about 5 bp for a borrower who wants to cover the shortfall in the money market. The estimate is much larger than the corresponding OLS-estimate. Likewise, the estimate of the lender liquidity position, at -1.73, is greater than the OLS-estimate. It is in line with expectations that the effect is greater for borrowers than for lenders since those in need of liquidity face a hard limit while those with surplus liquidity face a soft limit.

Still, while these figures suggest that finding liquidity is a less than frictionless process, they seem low enough for the money market to function well. A money market loan will still be an attractive source of funding relative to alternatives such as e.g. borrowing from the central bank

Table X: 2SLS-estimates

This table shows the results from a two-stage least squares estimation where the borrower's and lender's net payment flows on the day of the loan are used as instruments for the liquidity positions. Both first- and second-stage result are reported. The dependent variable in the second-stage regression is quoted in basis points. For details on the computation and measurement units of the independent variables, see section 2.2. t-statistics based on robust standard errors are in parentheses.

	1st stage: Liquidity position (B)	1st stage: Liquidity position (L)	2nd stage: interest rate
Liquidity position (B) - fitted	. (.)	. (.)	-6.00 (2.65)
Liquidity position (L) - fitted	. (.)	. (.)	-1.73 (5.39)
Net position (B) [10 bn]	0.02 (4.09)	0.01 (2.70)	0.1 (1.11)
Size (B)	0.27 (6.55)	-0.06 (1.33)	2.39 (2.44)
Tier 1 capital (B)	-0.42 (-2.34)	-0.22 (0.93)	-12.71 (2.52)
Net position (L) [10 bn]	0.00 (1.04)	0.03 (4.67)	0.2 (3.24)
Size (L)	-0.16 (5.17)	0.68 (14.60)	1.66 (2.05)
Tier 2 capital (L)	-0.31 (1.88)	-1.73 (6.74)	10.66 (2.34)
Loan size	-0.38 (69.13)	0.37 (53.42)	-1.70 (1.99)
Friday	0.04 (3.12)	-0.02 (1.08)	10.87 (35.69)
Total payments (t) [100 bn]	-0.01 (1.15)	0.07 (4.07)	3.6 (12.03)
Total payments (t-1) [100 bn]	0.00 (0.33)	0.00 (0.21)	1.84 (9.11)
Total payments (t+1) [100 bn]	0.02 (1.73)	0.08 (5.57)	-1.09 (2.98)
Gov't payment flow [100 bn]	0.11 (2.83)	0.3 (4.19)	9.70 (5.42)
Agg. CA balance [100 bn]	0.62 (11.59)	2.04 (22.92)	-21.01 (7.44)
Agg. net position [100 bn]	-0.04 (1.49)	0.17 (3.89)	-18.19 (17.52)
CDS (gov't)	-0.00 (2.06)	0.01 (18.77)	-0.08 (4.28)
Net payments (B, t) [10 bn]	0.25 (10.29)	0.02 (0.71)	()
Net payments (L, t) [10 bn]	-0.04 (2.51)	1.51 (18.31)	()
R^2	0.34	0.44	0.44
1st stage F-statistic	58.3	168.1	
N		40103	

against collateral. In the sample period (2005 to mid-2013) the rate at which banks could borrow from the central bank was on average 33 bp greater than the current account rate. In comparison, the average rate paid on money market loans, which do not require the posting of collateral, was 15 bp greater than the current account rate (see Table II).

Finally, we examine estimates across subsamples. As was this case with the OLS-estimates, the IV-estimation produces results that vary considerably. The estimates are given in Table XI. As before, the borrower liquidity position is significant in the crisis-period and in the period encompassing the European debt crisis, and now also in the period of negative interest rates.

The instrumental variables estimates are generally greater in magnitude than the corresponding OLS-estimates, and especially the estimates found in the financial and debt crises are large from an economic perspective. The figure for the negative interest rate period is not entirely comparable, because banks' current account limits were greatly increased during that period. In terms of actual liquidity, therefore, a change in the liquidity position during that period corresponds to a much greater change in liquidity.

Table XI: 2SLS vs. OLS estimates - subsamples
The table compares parameter estimates of the borrower liquidity position across subsamples when estimated using OLS and 2SLS. The pre-crisis period is dated from January 2005 to June 2007, the crisis period from August 2007- 9 October 2008, the period of government guarantees from 10 October 2008 to September 2010, the period encompassing the European sovereign debt crisis from October 2010 to 5 July 2012, and finally the period of negative interest is dated from 6 July 2012 to the end of the sample in June 2013. The OLS-estimates are based on the same model specification as in Table IV, column 1. The 2SLS-estimates are based on the same specification as in Table X. t-statistics based on robust standard errors are in parentheses.

	Pre-crisis	Crisis	Gov't guarantee	Debt crisis	Neg. interest rates
			IV-estimates		
Liquidity position (B)	1.91 (0.70)	-14.11 (3.82)	1.02 (0.17)	-11.36 (3.99)	-14.27 (4.20)
Liquidity position (L)	-0.52 (0.55)	-3.83 (2.31)	-2.55 (3.42)	-0.22 (0.57)	0.39 (0.34)
			OLS-estimates		
Liquidity position (B)	-0.06 (0.21)	-2.30 (5.04)	-0.31 (1.43)	-0.30 (1.98)	-0.41 (0.53)
Liquidity position (L)	-0.39 (2.41)	-1.25 (4.21)	-0.26 (1.65)	-0.05 (0.66)	0.96 (1.91)
N	11,800	6,408	11,534	8,299	2,062

2.5. The Decision to Borrow or Lend

In our analysis of the interest rate, we did not find evidence that credit risk, or at least regulatory measures thereof, directly affect rates for banks that are able to borrow, nor that there was an indirect effect via the liquidity positions. Perhaps, though, credit risk affects the decision to borrow or lend in the first place. For precautionary motives, riskier banks may choose to hold more liquidity and therefore have less need to borrow; and perhaps, holding more liquidity, they are more likely to supply it as lenders. These considerations suggest that we may again face a potential problem of bad controls if we include both the liquidity position of banks and credit risk variables.

The analysis in this section indicates that credit risk does influence the decisions to borrow and lend via the liquidity position. Unlike before our interest is not in the liquidity position itself. It is self-evident that the liquidity position must be a key determinant of borrowing and lending, since it is exactly to adjust their liquidity position that banks borrow and lend.

We first analyze probit models for each subsample and for both borrowers and lenders to get a sense of the determinants of the borrowing and lending decisions. In that analysis we simultaneously include the liquidity position and the tier II capital ratio of banks in the analysis. Subsequently, we examine how a broader set of credit risk variables work when the liquidity position is included and excluded.

One issue is whether to include fixed effects. If included, one can perfectly predict the participation decisions of the two largest banks, at least in most subsamples, since they participate virtually every single day. These banks must therefore be taken out of the analysis. If fixed effects are excluded, however, the model is likely to be misspecified. Excluding fixed effects may result

Table XII: The borrowing and lending decisions
This table reports estimates from probit models of the decision to borrow (top panel) and the decision to lend (bottom panel). For details on the computation and measurement units of the independent variables, see section 2.2. t-statistics based on robust standard errors are in parentheses. The full sample runs from January 2005 to June 2013. The pre-crisis period is dated from January 2005 to June 2007, the crisis period from August 2007- 9 October 2008, the period of government guarantees from 10 October 2008 to September 2010, the period encompassing the European sovereign debt crisis from October 2010 to 5 July 2012, and finally the period of negative interest is dated from 6 July 2012 to the end of the sample.

	Panel of borrowers						
	Full sample	Full sample	Pre-crisis	Crisis	Gov't guarantee	Debt Crisis	Neg. interest rates
Borrower (t-1)	1.48 (101.71)	1.11 (70.16)	0.80 (27.43)	0.84 (19.02)	1.01 (32.98)	1 (25.56)	0.74 (12.8)
Liquidity position	-0.41 (22.18)	-0.45 (22.19)	-0.83 (14.13)	-0.51 (11.49)	-0.30 (11.21)	-0.78 (10.41)	-1.61 (8.32)
Net position	0.23 (4.7)	-0.58 (9.19)	0.04 (0.19)	-0.55 (2.19)	-0.20 (2.45)	-0.95 (1.11)	-2.58 (0.66)
Size	0.23 (56.88)	0.47 (11.07)	-0.25 (1.26)	0.78 (2.25)	-0.34 (1.46)	0.43 (1.49)	-0.39 (0.75)
Tier II capital	-0.91 (6.98)	-0.13 (0.61)	1.01 (1.13)	-1.37 (1.47)	-3.84 (4.47)	1.99 (1.61)	-3.86 (1.25)
Agg. CA balance [100 bn]	0.3 (2.34)	0.09 (0.67)	-0.22 (0.63)	-0.51 (0.77)	0.46 (1.27)	0.73 (1.56)	-0.70 (2.37)
Agg. Net position [100 bn]	0.27 (4.94)	0.28 (4.88)	0.16 (1.13)	0.19 (1.1)	0.12 (1.28)	0.72 (5.47)	0.62 (2.84)
Friday	-0.48 (26.68)	-0.50 (26.16)	-0.55 (15.51)	-0.68 (12.11)	-0.62 (15.8)	-0.49 (10.9)	0.21 (2.88)
Gov't payments [100 bn]	0.62 (7.73)	0.68 (7.92)	0.55 (2.77)	0.31 (1.21)	0.66 (4.2)	0.84 (4.42)	0.33 (1.09)
Total payments (t) [100 bn]	-0.03 (1.55)	-0.02 (1.28)	0.01 (0.31)	0.06 (0.86)	-0.04 (1.06)	-0.10 (2.27)	0.15 (2.78)
Total payments (t-1) [100 bn]	0.02 (1.32)	0.01 (0.64)	-0.01 (0.2)	0.02 (0.34)	-0.04 (1.12)	0.11 (2.17)	-0.05 (0.94)
Total payments (t+1) [100 bn]	0.13 (6.71)	0.15 (7.47)	0.22 (4.93)	0.10 (1.49)	0.12 (3.22)	0.23 (4.76)	0.16 (2.35)
CDS (gov't)	0.00 (0.81)	0.00 (0.83)	-0.01 (0.28)	0.01 (1.78)	0 (0.51)	0.00 (0.94)	0.00 (1.24)
Bank fixed effects	No	Yes	Yes	Yes	Yes	Yes	Yes
N	71890	67782	16464	7084	16554	11518	2832
Pseudo R^2	0.49	0.56	0.48	0.41	0.50	0.50	0.67

	Panel of lenders						
	Full sample	Full sample	pre-crisis	early crisis	bank package I	post-BPI	neg. interest rates
Lender (t-1)	1.43 (79.53)	0.8 (37.45)	0.71 (18.2)	0.53 (9.08)	0.75 (18.45)	0.58 (12.02)	0.44 (3.92)
Liquidity position	0.18 (19.6)	0.23 (19.92)	0.26 (13.22)	0.32 (17.18)	0.21 (8.3)	0.32 (11.74)	0.91 (9.16)
Net position	0.67 (16.6)	-0.23 (4.09)	0.29 (1.49)	-0.91 (3.97)	-0.05 (0.63)	0.59 (0.95)	-2.52 (0.35)
Size	0.33 (80.28)	0.07 (1.06)	-0.08 (0.3)	1.79 (3.32)	-0.05 (0.18)	-1.18 (3.61)	-0.19 (0.14)
Tier II capital	-0.72 (3.69)	0.72 (2.07)	0.64 (0.42)	-0.46 (0.29)	-3.53 (3.14)	-0.81 (0.52)	-10.01 (1.98)
Agg. CA balance/100	-0.94 (6.14)	-1.51 (8.02)	-2.67 (5.9)	-2.57 (3.41)	-1.7 (3.58)	-3.14 (5.18)	-1.15 (2.6)
Agg. Net position/100	-0.16 (2.49)	-0.21 (3.01)	-0.1 (0.53)	-0.38 (1.68)	-0.21 (1.95)	0.02 (0.12)	-0.76 (2.13)
Friday	-0.18 (8.37)	-0.19 (7.78)	-0.17 (3.76)	-0.11 (1.73)	-0.28 (5.91)	-0.28 (5.25)	-0.23 (1.93)
Gov't payments/100	0.26 (2.69)	0.26 (2.41)	-0.14 (0.57)	-1.12 (3.57)	0.48 (2.44)	0.95 (4.38)	1.01 (2.28)
Total payments (t)/100	-0.01 (0.56)	0 (0.02)	-0.03 (0.64)	0.14 (1.69)	0.01 (0.33)	0.00 (0.10)	-0.04 (0.50)
Total payments (t-1)/100	0.02 (1.09)	0.02 (0.71)	0.05 (1.07)	0.18 (2.35)	-0.02 (0.39)	0.05 (1.08)	0.05 (0.59)
Total payments (t+1)/100	0.1 (4.93)	0.12 (5.17)	0.15 (2.7)	0.13 (1.58)	0.13 (2.98)	0.16 (3.22)	0.17 (2.09)
Agg. Credit risk	0.00 (1.34)	0.00 (1.56)	0.01 (0.49)	0.01 (1.2)	0.00 (0.7)	0.00 (0.31)	-0.02 (4.79)
Bank fixed effects	No	Yes	Yes	Yes	Yes	Yes	Yes
N	65728	65728	16464	5790	15486	13290	6372
Pseudo R^2	0.44	0.50	0.45	0.47	0.42	0.58	0.57

in a misspecification. In the case of interest rate regressions we saw, for instance, that one would obtain different estimates for the effect of the capital ratio depending on whether fixed effects were included or not. This could be explained if some unobservable heterogeneity, e.g. the quality of bank systems or management, would permit stronger banks to hold less equity. We thus prefer to include fixed effects, but also show results without fixed effects for comparison.

Table XII shows the results of the probit analysis for the full sample, with and without fixed effects, and for the subsamples with fixed effects.

The capital ratio does not appear to affect the decision to borrow directly. In fact, it is only significant in the sub-period where we would not expect credit risk to matter (and the parameter estimates is negative). Neither is there a clear pattern when we analyze the panel of lenders. If

Table XIII: Credit risk and the decision to borrow or lend
The table compares parameter estimates from probit models with and without the liquidity position included. The model specification is the same as in Table XII, but different credit risk measures are included. Estimates are not reported for the other control variables. The sample period is the full sample (January 2005 to June 2013).

Credit risk measure	Liq. position	Borrower panel	Lender panel
Tier 1 capital	Yes	-0.132 (0.61)	0.723 (2.07)
	No	0.869 (4.07)	-0.176 (0.55)
Tier 2 capital	Yes	-0.211 (0.92)	-0.188 (0.53)
	No	0.972 (4.39)	-0.376 (1.1)
Write-offs	Yes	0.123 (0.75)	0.061 (1.73)
	No	-0.322 (1.91)	0.073 (2.07)
Result	Yes	2.491 (3.76)	-0.315 (0.33)
	No	3.6 (5.65)	-0.94 (1.02)
Relative CR measure	Yes	0.242 (3.97)	0.298 (3.68)
	No	-0.079 (1.35)	0.398 (5.12)

we did not include fixed effects, we would even conclude that banks with less capital are more likely to borrow and lend. The other variables largely behave as expected; we discuss parameter estimates in more detail later in the context of the linear probability model.

Focusing on the full sample, Table XIII compare how parameter estimates for different measures of credit risk compare when the liquidity position variable is included and excluded, and a pattern emerges. In the borrower panel, we observe that the credit risk measures are often insignificant, and only in the case of the financial result is the sign as expected. When the liquidity position is not included, in contrast, the variables are generally significant and tell the same story: Healthier banks are more likely to borrow. Only in the case of the relative credit risk measure is the effect insignificant.

A qualitatively similar pattern emerges in the case of the panel of lenders. For each credit risk measure, exclusion of the liquidity position indicates that riskier banks are more likely to be lenders than their less risky counterparts. However, for only two of five variables is there a statistically significant relationship between bank health and the lending decision.

Finally, we estimate linear probability models for the borrower and lender panels. While such models suffer from conceptual problems, such as the possibility of predicting probabilities that are negative or exceed one, the results are easier to interpret than is the case with probit models. The results are reported both including and excluding the liquidity position variable in Table XIV.

The linear probability model generally agrees with the probit model about the determinants of loan decisions, but the quantities are easier to interpret in the linear probability model. Unsurprisingly, the liquidity position is significant: After all, banks who borrow generally do so because they need liquidity, while banks with surplus liquidity are more likely to be lenders. Another key determinant of the borrowing decision is past borrowing. The probability of a bank borrowing today is about a 40 percentage point higher if the bank borrowed the day before. This should not

Table XIV: The borrowing and lending decisions - linear probability model
This table shows estimates of the decision to borrow and lend in a linear probability model. For both borrowers and lenders the model is estimated without and with bank effects and, in the latter case, with and without the liquidity position included. For details on the computation and measurement units of the independent variables, see section 2.2. t-statistics based on robust standard errors are in parentheses.

	Borrower panel			Lender panel		
Borrower (t-1) / Lender (t-1)	0.49 (152.12)	0.38 (79.58)	0.44 (97.42)	0.46 (83.12)	0.26 (39.19)	0.3 (45.61)
Liquidity position	-0.06 (72.5)	-0.06 (31.85)	. (.)	0.03 (30.54)	0.05 (34.19)	. (.)
Net position [100 bn]	0.07 (9.17)	-0.05 (5.03)	-0.07 (7.11)	0.14 (17.17)	-0.05 (5.53)	-0.03 (3.05)
Size	0.05 (65.28)	0.04 (5.83)	0.02 (3.65)	0.06 (69.78)	0.00 (0.79)	0.02 (2.93)
Tier II capital	-0.10 (4.20)	0.02 (0.55)	0.15 (3.3)	-0.05 (2.76)	-0.11 (4.06)	-0.21 (7.22)
Agg. CA balance [100 bn]	0.04 (1.58)	0.02 (0.62)	-0.06 (2.59)	-0.08 (4.86)	-0.12 (7.44)	-0.06 (3.45)
Agg. Net position [100 bn]	0.05 (4.58)	0.06 (5.01)	0.07 (5.89)	-0.02 (1.87)	-0.02 (2.4)	-0.02 (3.13)
Friday	-0.11 (29.21)	-0.10 (29.33)	-0.10 (29.14)	-0.03 (10.01)	-0.02 (10.06)	-0.02 (9.69)
Gov't payments [100 bn]	0.13 (8.05)	0.14 (8.53)	0.17 (10.03)	0.05 (3.94)	0.05 (4.20)	0.03 (2.33)
Total payments (t) [100 bn]	-0.01 (1.72)	-0.01 (1.94)	-0.02 (4.24)	-0.01 (2.42)	-0.01 (2.46)	0.00 (0.13)
Total payments (t-1) [100 bn]	0.00 (1.26)	0.00 (0.19)	0.00 (0.75)	0.00 (0.01)	0.00 (0.35)	0.00 (1.02)
Total payments (t+1) [100 bn]	0.03 (7.39)	0.03 (7.56)	0.02 (5.37)	0.01 (4.4)	0.01 (4.38)	0.02 (5.97)
Agg. Credit risk	0.00 (0.66)	0.00 (0.61)	0.00 (0.8)	0.00 (0.88)	0.00 (1.34)	0.00 (1.19)
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Bank fixed effects	No	Yes	Yes	No	Yes	Yes
N		65728			71890	
R^2	0.48	0.52	0.48	0.48	0.56	0.53

come as a surprise; if a bank is hit by a negative liquidity shock one day, it will, absent a liquidity shock in the reverse direction or borrowing from another source, need to borrow the following day again to remain at the same level of liquidity.

This is also evident when evaluating the "Friday" variable, i.e. whether banks have access to central bank facilities on a given day. When banks have such access, they are about 10 percentage points less likely to borrow from other banks and about 2 percentage points less likely to lend to other banks. One way to put this figures into perspective is to compare to the unconditional probability of a bank in our panels borrowing or lending on a given day. Not counting the two largest money market participants, which borrow and lend essentially every day, the probability of a bank borrowing is 32.4 percent, while the probability of a bank lending is 10.1 percent.

There does appear to be a relationship between the capital ratio and the decision to borrow or lend. Consider the case of borrowers. When not including fixed effects, banks with more capital appear to be less likely to borrow. A possible explanation is the some unobserved feature of the banks, their "quality", say, permits certain "high quality" banks to hold less capital. At least, the negative relationship vanishes when fixed effects are included. As in the probit model, the sign changes when the liquidity position is excluded from the analysis, implying (more in line with prior expectations) that healthier banks are more likely to borrow. Our interpretation is that this is due to healthier banks choose, or can afford, to hold less liquidity since they will be able to obtain loans when faced with liquidity shocks.

Better capitalized banks tend to be borrowers, and less well-capitalized banks lend more. Moreover, this result is amplified, in the same direction as in the probit model, when the liquidity position is excluded from the model. A reasonable interpretation is that healthy banks choose, or can afford, to hold less liquidity. When the liquidity position is included, therefore, there is no significant relationship between the capital ratio and the decision to borrow.

2.6. Event Study Evidence

In this final section we briefly consider some event study evidence. There were two major events which seem especially likely to have affected the Danish interbank market during the financial crisis. The first was the default of Roskilde Bank, the 8th largest bank in Denmark at the time, and the second was the bankruptcy filing by Lehman Brothers on 15 September 2008. Roskilde Bank was taken over by the Danish Central Bank and an association of banks on 24 August 2008[13], but Roskilde Bank had already begun receiving emergency funding on 10 July 2008.

We consider these three dates as event dates and consider the behavior of the money market around these dates. When performing regressions considering dates around these events, there are clear spikes in interest rates only for loans beginning on July 11 and August 26th, perhaps because many of these loans are agreed a day in advance, corresponding to the actual default dates. There are no significant effects around Lehman's default. We therefore focus on the dates following the two Roskilde events.

We are naturally interested in questions such as whether riskier banks pay premia in times of stress. However, as we have argued in previous sections, our measures of credit risk based on bank balance sheet information may not be particularly good measures of credit risk. In this section we therefore take a slightly different approach. Supposing that banks which are perceived to be riskier do, in fact, pay higher rates, we should be able to capture this through the estimates of bank fixed effects. We therefore estimate the bank fixed effects using data from period from March 2007, roughly corresponding to earliest stage at which problems in the financial system became widely evident, to February 2008. These estimates are then used a measures of credit risk in regressions encompassing the period March 2008 to February 2009, placing the event dates of interest close to the middle of this period.

The results of the event study are reported in Table XV. Banks which pay higher rates before the event period also pay rater higher in the event period. To put the numbers in perspective, the

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[13] This was during the weekend. We look at the following days.

Table XV: Event study evidence
This table shows the effects of credit risk and the liquidity position on respectively interest rates and access to the interbank market on 11 July 2008 and 26 August 2008, the days after news about difficulties and default at Roskilde Bank. The credit risk of each bank is defined as the individual bank fixed effect found from a regression on interest rates, including other controls, in the period from March 2007 to February 2008. The results in the "Interest rates"-column are based on regressions in which the dependent variable is the money market rate less the central bank current account rate. Also included in the regression, in addition to the reported variables, are the same controls as in the base specification (except the tier 2 capital ratio) and time fixed effects. The "Access"-column shows the result of a panel probit model in which the dependent variable is whether a bank accesses the money market on a particular day. The control variables are the same as in the base specification of the probit model (except the tier 2 capital ratio) used elsewhere in the paper. The sample period runs from March 2008 to February 2009. t-statistics based on robust standard errors are in parentheses.

	Interest rates	Access
Credit risk	1.12 (17.97)	0.01 (3.11)
Liquidity position	-1.72 (2.63)	
July 11	21.89 (3.27)	0.92 (1.09)
* Credit risk	0.66 (1.11)	0.07 (1.7)
* Liq. Position	-16.18 (1.35)	
August 26	50.75 (11.62)	-0.64 (1.02)
* Credit risk	0.22 (1.14)	-0.03 (1.22)
* Liq. Position	-11.38 (2.56)	
Time FE	Yes	Yes
N	7,200	5,580
R^2 / pseudo R^2	0.48	0.49

standard deviation in the credit risk measure is about 10 basis points, implying that a one standard deviation change in the credit risk measure changes rates by 11.2 basis points in the event period. We are more interested in the effects on the particular event dates, however. Average rates are substantially higher than normal on these dates, especially following the actual takeover of Roskilde Bank. The interaction effects all go in the expected direction - the credit risk measure and the effect of being short on liquidity are amplified - but the effects cannot be measured precisely. We do not observe strong effects on banks' access to the market. These findings are somewhat similar to these in Afonso et al. (2011) who find that banks mainly adjust interest rates around the major event in the US, the Lehman default.

2.7. Conclusion

Banks turn to the overnight interbank market to absorb liquidity shocks. We assess the efficiency of this market by analyzing how a bank's liquidity position affects the interest rate it must pay. Since a liquidity inflow to one bank is an outflow to another bank, a healthy bank faced with a liquidity need should be able to find liquidity and, due to competition among banks with excess liquidity, pay a rate equal or close to the opportunity cost of holding liquidity for those with liquidity to spare.

On average, banks in need of liquidity pay only a small premium relative to those with ample liquidity. For instance, a bank with a liquidity position of zero, the amount of liquidity the bank must hold at a minimum, pays less than a single basis point more than a bank with a liquidity position of one, the amount it is permitted to hold. Yet, while banks short on liquidity may not pay higher in many cases, they do so in certain circumstances. When aggregate liquidity scarce, when liquidity is needed more urgently, and payment activity is large, the effects of having little liquidity are more pronounced, and the magnitudes are in the order of a few basis points. These are still relatively low figures when compared to the observed variation in money market rates. To give some perspective, the standard deviation of the interest paid on a loan less the average rate paid on the day of the loan is 17 basis points.

A concern is that liquidity and credit effects are being confounded. For instance, riskier banks may choose to hold more liquidity for precautionary reasons. An implication would be that excluding the liquidity position from regressions should produce different estimates for variables related to credit risk. We do not find any evidence of such an effect when using regulatory measures of credit risk such as bank capital ratios. Another possibility is that we fail to adequately measure credit risk because capital ratios (and other measures based on financial statements) are imperfect and are only sampled on a quarterly basis. To address this concern we take an instrumental variables approach to estimating the effect of the liquidity position. The IV-estimate of the borrower's liquidity position is about 9 basis points, substantially higher than a regular OLS-estimate of less than a single basis point. This estimate further masks differences across sub-samples. The liquidity position mainly appears to matter in the crisis period and in the period encompassing the European sovereign debt crisis. Pre-crisis and during the period in which money market loans were covered by a government guarantee, banks did not pay significantly higher rates when they were in need of liquidity.

While regulatory measures of credit risk do not affect money market rates, there is some evidence to suggest that they influence participation. At first glance it appears that banks with more capital are less likely to borrow than those with less capital. If one controls for bank heterogeneity by including fixed effects, however, this effect vanishes. In that case we show that an increase in the capital ratio is associated with an increase in the likelihood of being a borrower while a decrease is associated with an increase in the likelihood of being a lender. This mainly reflects an indirect effect. Banks with higher capital ratios choose to hold less liquidity and therefore more frequently need to access market; conversely, banks with less equity capital hold more liquidity and therefore tend to have liquidity to lend.

Our analysis contributes to an understanding of - and thereby potentially have implications for - how institutional details such as the monetary policy rules set by the central bank affect money market activity. As an example, we observe that money market rates are about 10 basis points higher on days when lenders can place money in certificates of deposits (which typically yield 10 basis points more than money deposited in a bank's current account), while borrowing and lending activity is dampened. Also, we show throughout the paper that aggregate liquidity and payment activity affects the functioning of the money market, and these are factors over which the central bank and the government can exert influence.

Collateralized Lending and Central Bank Collateral Policy

ABSTRACT

This paper examines a model of collateral-based lending and central bank collateral policy. Firms cannot pledge their income, but secure credit through collateral. Banks can become informed about collateral quality prior to lending or lend based on the expectation of collateral being adequate. Uninformed lending allows firms to use more capital, but entails fragility. Central banks generally use collateral policy to further information acquisition. When credit constraints arise, however, central banks support uninformed lending. The model may help explain features of collateral policy such as central banks' use of narrow and broad sets of eligible collateral in good and bad times respectively.

Keywords: Banking; Collateral policy; Central Banks

JEL-classification: E42; E58; G01; G21

3.1. Introduction

Collateral is important to the provision of credit in the economy. Azariadis et al. (2015) report that about 55% of non-financial firms' liabilities are secured[1], and households and financial institutions likewise rely heavily on collateral, for example to finance housing and in repurchase agreements. The use of collateral, however, does not insulate agents from risks; secured credit too can be subject to runs (Gorton and Metrick, 2012).

Gorton and Ordoñez (2014) describe one mechanism through which "collateral crises" arise: Commonly, the collateral which supports lending is of such quality that lenders face few incentives to undertake costly information acquisition and determine its exact composition. Some low quality collateral is therefore pooled with high quality collateral. This increases the availability of credit, but is a source of fragility. If there is a perception that collateral quality has deteriorated, lenders may suddenly want to become informed about actual collateral quality and will no longer provide funding on the same terms as earlier: Those with bad collateral lose funding, and those with good collateral must compensate lenders for acquiring information. The collapse of the market for asset-backed commercial paper was a case in point. Kacperczyk and Schnabl (2010) write: *"Also, before the financial crisis, most investors believed that commercial paper almost never defaults and therefore had little incentive to invest in information gathering [...]. However, during the crisis, investors decided to invest more resources in information-gathering activities because the value of commercial paper was more sensitive to new information."*

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[1] Using earlier data from 1977-1988, Berger and Udell (1990) find that nearly 70% of commercial and industrial loans were made on a secured basis based on a sample of more than a million bank loans.

This first part of the paper examines when credit constraints arise under collateralized lending. The model is based on Gorton and Ordoñez (2014), which I extend in three ways: First, I relax an assumption that lenders must be making zero profits due to competition. In fact, borrowers with highly profitable projects are better off leaving some profits to lenders in order to relax credit constraints. I also introduce an information externality. Roughly speaking, the idea is that agents individually face more uncertainty about collateral quality if there is little information being gathered in aggregate. Third, a central bank is introduced in the second part of the paper.

The central bank uses collateral policy to affect banks' information-gathering incentives. Banks need to make payments and can either hoard liquidity, which limits lending, or borrow from the central bank. The central bank can exploit this by making a certain degree of information acquisition a prerequisite for collateral eligibility. More information is associated with a lower probability of shocks occurring, but uninformed lending generally allows agents to use more capital. When collateral quality is high, central banks use policy to induce information acquisition to limit risks while preferring uninformed lending when credit constraints arise due to perceptions of low collateral quality.

These findings are similar to instances of actual policy. There are various cases of central banks using transparency requirements as a means of limiting systemic risks; for example, some have made information disclosure requirements (e.g. about the collateral underlying securitized products) a prerequisite for central bank eligibility (Zorn and Garcia, 2011). On the other hand, central banks' crisis responses have encouraged less information-intensive lending. Some of the Federal Reserve's crisis facilities, for instance, included non-recourse provisions. Under the Term Asset-Backed Securities Loan Facility, the Fed made non-recourse loans to holders of newly issued asset-backed securities, with those particular securities pledged as collateral. The non-recourse feature insulated the users of the facility from tail risks. They could walk away from the loan and hand over the collateral, thus facing weaker incentives to examine collateral quality.[2]

The setting in Gorton and Ordoñez (2014) is a useful starting point for thinking about credit and collateral policy for at least three reasons. First, it is a model of collateralized lending. Second, credit constraints, which resemble ”panics”, emerge in the model as small changes in perceptions of collateral quality can lead to sharp contractions in credit. And third, a distinction is made between informed and uninformed lending which allows one to think about the consequences of more or less information acquisition.

In the model, borrowers (”firms”) need capital to finance projects, but cannot pledge income to lenders (”banks”). They have access to collateral (of uncertain value), which permits them to secure credit. The value of the collateral is unrelated to their project. The collateral can be thought of as representing land or real estate. Banks have an informational advantage in that they can, at a cost, verify the true value of the collateral. If they verify the true collateral quality, they lend only when the collateral is found to be good.

Since it is costly to verify collateral quality, banks may lend solely based on the expectation of the collateral being good. This allows firms to obtain more credit, but creates uncertainty about the true value of the collateral because no one verifies it. A collective lack of information gathering creates fragility as new information in the form of signals can lead to large revisions in beliefs, which in turn may cause funding withdrawals.

Interestingly, credit constraints affect less profitable projects the most, even though a) firms only secure loans because they have collateral and b) project quality is unrelated to collateral value. Firms would be better off if banks lent solely based on the expectation of their collateral being good. However, when collateral quality is more uncertain, banks have a strong incentive to verify it prior to lending. To avoid this, firms may respond by seeking smaller loans, making it less attractive for banks to incur fixed information costs. Firms become credit constrained in the sense that they borrow less than is possible given the amount of collateral they have and the technology available to them. Rather than seeking smaller loans, however, firms with more profitable projects forgo some profits to ensure that credit is always available to them.

Additional information acquisition entails a positive externality when collateral quality is high, but a negative externality when credit constraints bind. This reflects a trade-off between fragility and the amount of capital which can be employed when no shocks materialize. When credit constraints are present, the marginal value of additional capital is high, and further risk-taking in the form of uninformed lending is preferable. These results may help explain why central banks normally encourage information production, but favor less information-intensive lending in crisis periods.

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[2] When the Fed introduced its first crisis facility, the Term Auction Facility, Greg Ip wrote a post on the Wall Street Journal’s Real Time Economics blog with the title ”Bye-Bye Bagehot?” (15 January 2008), in reference to Bagehot’s dictum that a central bank should respond to a panic by lending freely at a high rate against *good collateral.* In fact, (Bagehot, 1873, p. 198) emphasized that a central bank should lend against ”what in ordinary times is reckoned a good security.”

Among the key results are the following: 1) there is an optimal degree of information acquisition which a central bank would like to achieve; 2) in some cases, for example when bank reserves are ample, the central bank cannot induce as much information acquisition as is optimal; and 3) the model points to preference for collateral characterized by high information costs, which are less plagued by asymmetric information (or are "information-insensitive" in the parlance of Gorton and Ordoñez (2014)). Such a description fits safe debt securities which are typically the preferred collateral of central banks.

In terms of related literature, the classic reference on collateral policy is Bagehot (1873). More recent contributions include e.g. Ashcraft et al. (2010) who link haircuts and expected returns and Cassola and Koulischer (2014) and Koulischer (2015) who discuss the role of collateral policy when interest rate policy cannot be used to deal with asymmetric shocks such as in a currency union. Similar to this paper, Koulischer and Struyven (2014) address the issue of why central banks loosen collateral standards when credit constraints arise. The friction in their paper is moral hazard in the interbank market. Also related is Bindseil (2013) who discusses the role of collateral policy in containing asset fire sales. Chailloux et al. (2008), Cheun et al. (2009), and BIS (2013) describe the collateral frameworks of major central banks. For a recent overview of the literature on central bank collateral frameworks, see Nyborg (2015). Collateral is also interesting in its own right due to its role in explaining macroeconomic fluctuations (e.g. Kiyotaki and Moore, 1997).

The paper further relates to the literature on information externalities. There idea that the information-gathering efforts of some affect the outcomes of others has many applications. These range from how to presence of informed consumers improve terms for uninformed consumers (Salop and Stiglitz, 1977) to IPOs (Benveniste et al., 2002), bank runs (Nikitin and Smith, 2008), disclosure of financial information (Kurlat and Veldkamp, 2015), etc. The idea is also central to the notion of market efficiency (Grossman and Stiglitz, 1980; Gârleanu and Pedersen, 2016). Information is important in the paper in another way as well: Collateral is characterized by an information cost which may be viewed as a measure of information asymmetry or "information-sensitivity" (Gorton and Ordoñez, 2014; Dang et al., 2015).

The rest of the paper is organized as follows. Section 3.2 describes the model. Section 3.3 discusses collateralized lending. Central bank collateral policy is examined in Section 3.4. Section

3.6 concludes. Proofs are in the appendix.

3.2. Model

The basic model features a unit mass of risk-neutral borrowers (”firms”) and lenders (”bank”). A central bank is introduced in Section 3.4. Firms have access to a project, but lack capital (numeraire) to finance it. Each firm is randomly matched with a bank. Banks are competitive and offer contracts to firms.

3.2.1. Technology, informed and uninformed lending

The description of the technology and possible loan types follows Gorton and Ordoñez (2014). Specifically, firms require capital to undertake their projects which generate income according to a stochastic Leontief technology. Capital K produces:

$$F(K) = A \begin{cases} min\{K, K^\star\} & \text{with prob. } q \\ 0 & \text{with prob. } 1-q \end{cases} \tag{1}$$

Production only takes place when $qA > 1$; otherwise, either firms or banks would be making losses if lending took place. Also, if there were no constraints on the choice of K, the optimum would be to use as much capital as possible, though at most $K^\star$.

Banks have capital $\bar{K}$ ($> K^\star$) which they can lend to firms. Firms' output cannot be pledged to banks, and they therefore cannot make promises of repayment based on their income. This creates a role for collateral. Firms have access to collateral, which pays:

$$\widetilde{C} = \begin{cases} C & \text{with prob. } p \\ 0 & \text{with prob. } 1-p \end{cases} \tag{2}$$

Collateral quality p is a key state variable in the model. All collateral shares the same p ex ante, but realizations are independent. It is also assumed that $C > K^\star$, implying that collateral of high quality can sustain the optimal production level.

Prior to lending banks can learn whether the collateral is good or bad by producing information at cost γ. Information can only be produced at the beginning of the period. Banks can commit to acquire information and verify collateral quality, but cannot commit not to acquire information.[3]

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[3] The assumption that banks can commit to verifying the collateral quality can be replaced by an incentive-compatibility constraint, a point I discuss in the appendix. Banks' informational advantage also explains why firms do not sell their collateral to finance projects as banks would also have a strong incentive to verify the collateral quality prior to a purchase, preventing firms from selling at fair value.

In summary, banks have three possible actions available to them. They can (1) commit to verifying the collateral quality prior to lending ("informed lending"); (2) promise to lend without verifying the collateral quality ("uninformed lending") and keeping that promise; or (3) promise to lend without acquiring information, and secretly learn the collateral quality prior to lending (in which case they only lend if the collateral quality is good). Firms prefer for banks to lend in all states since their projects are profitable whether or not the collateral is good. They must therefore incentivize banks not to secretly verify the collateral quality.

Banks offer two types of contracts, one specifying that information is to be acquired, the other that it should not. Firms choose the loan contract, informed or uninformed, which maximizes profits. A contract is a treble (K, R, x) specifying a loan amount, K, a promised payoff, R, and a fraction of collateral, x, to be handed over in case of default.

3.2.2. Information and signals

An outcome of the model is that agents will not gather information for a range of collateral qualities. They have some belief (p) about collateral quality, but this belief could be erroneous. If information is not entirely private, banks may learn from the information-gathering effort of others. It is then natural to think of a more information as corresponding to a more precise estimate of p. This idea is captured in a reduced-form way through the introduction of a signal, which is observed by those lenders who do not gather information. Concretely, I define $1 - \alpha$ as a measure of information in the economy and let $\eta = 1$ be the event that a signal is observed. The conditional probabilities of signals being observed are:

$$Pr\{\eta = 1 | \widetilde{C} = 0\} = \alpha \tag{3}$$

$$Pr\{\eta = 1 | \widetilde{C} = C\} = 0 \tag{4}$$

If there is full information ($\alpha = 0$), the signal is never observed. With less than full information, banks conclude that collateral is bad whenever a signal is observed. On the other hand, if no signal is observed, agents revise upwards their beliefs about collateral quality. I let $\underline{p} \equiv Pr\{\eta = 0\}$ and $\overline{p} \equiv Pr\{\widetilde{C} = C | \eta = 0\}$ be the respective probabilities of no signal being observed and of the collateral being good conditional on no signal is observed. Initially, α is treated as an exogenous parameter. When the central bank is introduced in Section 3.4, it will be defined as the fraction of uninformed lenders.

The above formulation, while evidently stylized, has some noteworthy features. First, it fits the idea of agents having a more precise estimate of the collateral quality. A higher α corresponds to greater (ex post) dispersion in beliefs about collateral quality, and it does so in a tractable way: it is simpler to work with the case where p becomes either $\overline{p}$ or 0 rather than e.g. a whole distribution of collateral qualities. Second, expected collateral quality is ex ante independent of α. Third, it captures the idea of a trade-off between fragility and the amount of capital available. This idea is conveyed e.g. in the dynamic extension to the model in Gorton and Ordoñez (2014) where the mechanism is pooling of good and bad collateral and in Biais et al. (2015) where a period of tranquility can spur the entry of agents who are less diligent at managing risks, which magnifies the effects of shocks.

3.2.3. Timing of events

Firms are initially matched with banks who offer contracts, with firms choosing the best. This is followed by a period during which banks can become informed about project quality, either because it has been agreed upon or secretly. If information acquisition has been agreed upon and the collateral is found to be good, capital is transferred, and nothing further happens until payoffs are realized. After the period during which information acquisition is possible, there is period during which investment is still reversible, so banks can withdraw funding at no cost.[4] Uninformed lenders do so whenever they observe the signal. Subsequently, and this is explained more fully when the central bank is introduced, banks may need to make a payment, which requires them to have capital at hand. Finally, project payoffs are realized and payment is made or collateral is transferred. The timing is depicted in Figure 3.1.

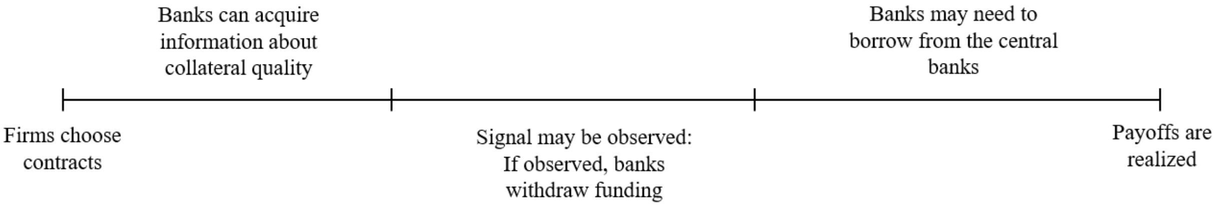
Banks can acquire information about collateral quality
Banks may need to borrow from the central banks
Firms choose contracts
Signal may be observed: If observed, banks withdraw funding
Payoffs are realized

Figure 3.1: Timing of events

One can think of the setting as describing a firm which seeks to finance a new project and approaches a bank for a loan, offering existing assets such as land or real estate as collateral. They can agree for the bank to investigate the collateral, for example by physically inspecting it (thus making the act of information acquisition verifiable). However, the firm has no means of preventing the bank from performing its own analysis of the collateral, except through incentives. Of course, whenever the collateral is found to be good, investment can proceed. Uninformed lending, on the other hand, is potentially affected by the arrival of new information. The implicit assumption is that debt is short-term which creates refinancing risk as debt needs to be rolled over. If bad news arrive at a later stage, though before investments become irreversible, banks withdraw funding early, leaving good projects unfinanced. Finally, at a later stage, banks may face a temporary need for money due to an unrelated payment shock. In that case it is helpful if they are able to borrow from the central bank, using the secured loan as collateral.

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[4] The assumption that banks can recoup their invested capital could be modified such that withdrawal of financing entailed some loss. For our purposes it suffices that withdrawal of funding is costly for firms because some profitable investments are not being undertaken.

3.2.4. Equilibrium

I formally define an equilibrium once a central bank is introduced (in Section 3.4). For now and more informally, an equilibrium is defined as a pair of contracts (K, R, x), one representing informed and the other uninformed lending, of which firms choose the one maximizing profits. These contracts must satisfy a number of constraints. First, the amount of collateral a firm can promise away is limited by the amount of collateral it has:

$$x \leq 1 \tag{5}$$

Second, the borrower cannot use more capital than the first-best level capital:

$$K \leq K^{\star} \tag{6}$$

Third, there is a participation constraint. A bank must at least break even in expectation when lending. Fourth, there is an incentive-compatibility constraint, which applies only to uninformed lenders. A bank must not have an incentive to deviate by verifying the true collateral value and lending only when the collateral is found to be good. The participation and incentive-compatibility constraints are described in the following sections.

3.3. Collateralized lending: loan contracts and welfare

In this section, I examine when credit constraints arise under collateralized lending. By credit constraints, I refer to a situation in which firms borrow less than would be the case if there were no incentive problems. The analysis proceeds by first characterizing the optimal contracts with and without information acquisition. The preferred contract can then be found by comparing firm expected profits under each of these contracts. Thereafter the welfare effects of more or less information are analyzed. In this first part of the paper, the central bank plays no role, and α, the parameter representing the intensity of the information externality, is treated as exogenous.

3.3.1. Contract with information acquisition

The contract with information acquisition is the same is in Gorton and Ordoñez (2014) as neither the signal nor incentive problems affect this contract, but for completeness it is also described here. If agents agree to information acquisition, they already know whether the collateral is good or bad when the signal arrives, and their choices are thus independent of the signal. Profits from informed lending are given by:

$$E[\Pi_I] = p\left[q(AK - R) + (1-q)(-xC)\right] \tag{7}$$

Projects are only undertaken when collateral is found to be good (with probability p), and the project is successful with probability q in which case the payoff is AK. Banks receive either R or xC depending on whether the project is successful or not. Banks' participation constraint is:

$$p(qR + (1-q)xC - K) \geq \gamma \tag{8}$$

The left-hand side tells us that projects are financed with probability p in which case capital is always provided while agents are paid when the project succeeds (with probability q) and receive collateral otherwise (with probability $1-q$). The expected payoff must be sufficient to cover the information cost γ. There are no incentive problems since information acquisition is verifiable, and so the participation constraint must always bind.[5]

To solve for the optimal contract, one can first impose the restriction $R = xC$. If it were the case that $xC > R$, the firm would always prefer to sell the collateral in case of project failure at the end of the period and repay R instead of handing over part of the collateral at the end of the period. Conversely, if $xC < R$, it would always be advantageous to simply hand over the promised share of the collateral. One can then use this restriction and the binding participation constraint to see that $E[\Pi_I]$ is maximized by choosing K as large as possible subject to the constraint $x \leq 1$.

No contract is possible when the collateral quality (p) is very low ($p \leq \frac{\gamma}{(qA-1)C}$) because firms cannot compensate banks for the fixed information cost. When the collateral quality is not too low, the optimal contract is given by $\left(K = min\{K^\star, C - \frac{\gamma}{p}\}, R = K + \frac{\gamma}{p}, x = \frac{pK+\gamma}{pC}\right)$. The choice of capital reveals that lending can either be limited by $K^\star$ or the amount of collateral available. If information costs are high or collateral is limited (low C or p), collateral is the limiting factor. Specifically, as long as $p \geq \frac{\gamma}{C-K^\star}$, the first-best level of capital is feasible. The collateral share,

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[5] Since the optimal contract leaves banks with zero profits when collateral is good, the banks would clearly be making a loss if they claimed the collateral to be good when, in fact, they had found it to be bad.

x, is set such that banks make zero profits. If information costs are high, they must therefore be promised more collateral.

The case of a binding collateral constraint occurs if $p < \frac{\gamma}{C-K^\star}$. Moreover, if the collateral constraint is binding, it must be the case that $\frac{\gamma}{C(qA-1)} \leq p$ in order for the contract to be profitable for firms. To limit the number of cases under consideration, I will assume that $C(qA-1) < C-K^\star$: This ensures that $K = K^\star$ is chosen whenever informed lending is profitable. In that case the payoff to banks is $R = xC = K^\star + \frac{\gamma}{p}$. In words, they are being compensated for the capital they put into projects and must be paid interest, reflecting the fact that they must pay an information cost for which they are only compensated a fraction p of the time. Firm profits are then given by:

$$E[\Pi_I] = p(qA-1)K^\star - \gamma \tag{9}$$

The optimal contract under informed lending is given in Lemma 1.

Lemma 1. *The optimal contract under informed lending maximizes expected firm profits (7) subject to (5), (6), and (8). It is given by:*

$$(K, R, x) = \left(K^\star,\ K^\star + \frac{\gamma}{p},\ \frac{pK^\star + \gamma}{pC}\right) \tag{10}$$

provided that $p(qA-1)K^\star - \gamma \geq 0$. *Otherwise, no contract is possible.*

In the appendix I discuss how the assumption that information acquisition, when agreed upon, is verifiable can be replaced by an incentive-compatibility constraint. For example, one could imagine banks claiming to have found the collateral to be good without actually learning its value. (Though, a simple way for firms to avoid this problem would be to always hand over the promised fraction of the collateral rather than making payment.)

To ascertain whether information acquisition is, in fact, optimal, the profits from a contract with information acquisition must be compared to those from a contract without information acquisition.

3.3.2. Contract without information acquisition

Unlike in the above case, the characterization of the contract without information acquisition differs from that in Gorton and Ordoñez (2014), and it does so for two reasons. First, they impose a zero-profit condition when it may in fact be optimal for firms to leave some profits for banks when projects are highly profitable. Second, the effects of the signal must be taken into account when characterizing the optimal contract. The optimal contract is found by maximizing firm profits subject to the collateral constraint, capital use not exceeding the first-best, and the participation and incentive-compatibility constraints (which are specified in the following).

When a signal is observed, funding is withdrawn and neither banks nor firms make any profits or suffer losses. On the other hand, with probability $\underline{p}$ no signal is observed, and agents' update their beliefs about the collateral quality to $\overline{p}$. This implies that any contract which is not terminated early should be based on that probability.

The objective of the firm is to maximize expected profits from uninformed lending, and these are given by:

$$E[\Pi_{UI}] = \underline{p}\,(q(AK - R) + (1-q)(-\overline{p}xC)) \tag{11}$$

This equation tells the following: First, profits only occur when the signal is not observed (i.e. with probability $\underline{p}$). In that case, the project succeeds with probability q and fails with probability $1-q$. Since the project is only financed when the signal is not observed, the expected value of the collateral, conditional on financing taking place, is $\overline{p}xC$. Also, using an argument analogous to that for the contract with information acquisition, we can impose the restriction $R = \overline{p}xC$. Note furthermore that it is optimal for the firm to make payment from output whenever it can. The reason banks may want to deviate and learn the true collateral is that they obtain excess profits when firms default and the banks obtain the collateral which they, unlike the firms, know to be good. If firms were to hand over the collateral rather than making payment, they would be strengthening banks' incentive to deviate.

The bank's participation constraint is $(1-\underline{p})0 + \underline{p}(qR + (1-q)\overline{p}xC - K) \geq 0$, which reduces to:

$$\overline{p}xC \geq K \tag{12}$$

while the incentive-compatibility constraint reads:

$$\overline{p}xC - K \geq p(qR + (1-q)xC - K) - \gamma \tag{13}$$

The left-hand side expresses the profits from lending uninformed while the right-hand side are the profits associated with deviation. Here the critical fact is that at the point in time when banks can deviate, their belief about the collateral quality is still p. Note also that the state in which banks can potentially profit from deviating (by learning the collateral value before choosing whether to hand over the capital) is that in which projects fail. In that case they obtain the collateral which they, unlike the firms, know to be good.

Finally, we can express the updated probabilities $\underline{p}$ and $\overline{p}$ in terms of α. Application of Bayes' rule shows that if no information shock occurs, agents revise the probability that collateral is good to be

$$\overline{p} \equiv Pr\{\widetilde{C} = C | \eta = 0\} = \frac{p}{\underline{p}} \tag{14}$$

where the probability that no shock occurs is given by

$$\underline{p} \equiv Pr\{\eta = 0\} = p + (1-\alpha)(1-p) \tag{15}$$

If $\alpha = 0$, signals are never observed and there is no updating of beliefs. If, on the other hand, only some agents gather information, signals are observed with probability $Pr\{\eta = 1\} = \alpha(1-p)$. Note that the collateral is no worse in expected terms ex ante: The unconditional probability that the collateral is good is the probability that no shock occurs, i.e. $Pr\{\eta = 0\} = p + (1-\alpha)(1-p)$ multiplied by the updated probability that the collateral is good, $Pr\{\widetilde{C} = C|\eta = 0\}$. This product is p.

Having specified the elements of the problem, the optimal contract can now be derived (see the appendix). It is described in Proposition 1.

Proposition 1. *The optimal contract under informed lending maximizes expected firm profits (11) subject to (5), (6), (8), and (13). If either* $qA - \frac{1}{1-(1-\alpha)(1-q)} \leq 0$ *or if* $\frac{\gamma}{(1-\alpha)(1-p)(1-q)} \geq min\{\overline{p}C, K^\star\}$*, the bank's participation constraint always binds, and the optimal choice of capital is given by:*

$$K = min\left\{\overline{p}C,\ \frac{\gamma}{(1-\alpha)(1-p)(1-q)},\ K^\star\right\} \tag{16}$$

while the associated collateral shares and promised repayment amounts are defined by $x = \frac{K}{\overline{p}C}$ *and* $R = \overline{p}xC$*. Otherwise, the incentive-compatibility constraint binds, and the optimal choice of capital is*

$$K = min\left\{\overline{p}C\left[1-(1-\alpha)(1-q)\right] + \frac{\gamma}{1-p},\ K^\star\right\} \tag{17}$$

with collateral shares, $x = \left\{1,\ \frac{K^\star - \frac{\gamma}{1-p}}{(1-(1-\alpha)(1-q))\overline{p}C}\right\}$*, and promised payments,* $R = \overline{p}xC$*.*

It is instructive to study the conditions under which the various constraints bind. To do so, we must understand the economic meaning of the expressions in the proposition. The expression $qA - \frac{1}{1-(1-\alpha)(1-q)} \leq 0$ relates to the profitability of projects. For example, in the full information case ($\alpha = 0$), it reduces to a question of whether $q^2A - 1$ is positive or negative, i.e. whether projects are highly profitable or merely somewhat profitable. The second parameter restriction, $\frac{\gamma}{(1-\alpha)(1-p)(1-q)} \geq min\{\overline{p}C, K^\star\}$, describes a set of collateral qualities. This inequality holds if either p is low or high, but may not hold for intermediate values of p when collateral quality is more uncertain.[6]

A graphical depiction of when the various constraints bind for the optimal contract without information acquisition is given in Figure 3.2.

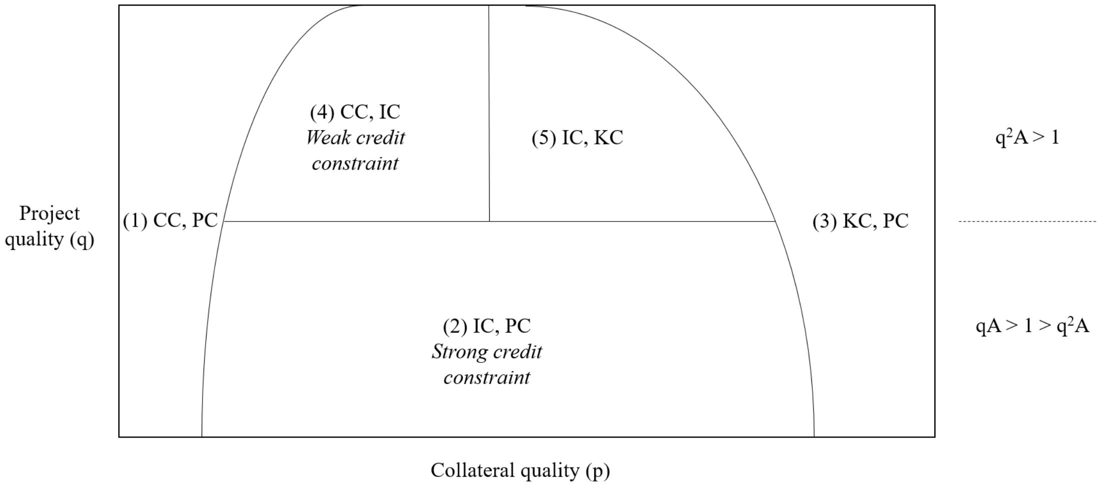

Figure 3.2: Constraint regions. The figure depicts which constraints binds depending on project and collateral quality in the full information case ($\alpha = 0$). There are five cases of binding constraints: (1) the participation constraint and the collateral constraint bind; (2) the participation constraint and the incentive-compatibility constraint bind; (3) the participation constraint and the first-best level of capital is used; (4) the incentive-compatibility constraint and the collateral constraint bind; and (5) the incentive-compatibility constraint and the first-best level of capital is used.

It is exactly the case of intermediate collateral qualities, which is interesting. If there were no incentive issues, the optimal contract would entail $K(p, \alpha) = min\,\{\overline{p}C, K^{\star}\}$, but in some cases less capital is used when the incentive-compatibility constraint binds. If projects are highly profitable ($qA - \frac{1}{1-(1-\alpha)(1-q)} \geq 0$), it is feasible to use capital in excess of $\frac{\gamma}{(1-\alpha)(1-p)(1-q)}$, which otherwise represents an upper bound on the amount of capital which can be used. This means that credit constraints are weaker for highly profitable projects than for less profitable ones. In fact, the proposition tells us that the first-best level of capital may even be reached for highly profitable projects when incentive problems are present. This observation is highlighted in the following corollary.

Corollary 2. *Credit constraints, the use of less capital than would be feasible if there were no incentive problems, are more pronounced for less profitable projects (for which* $qA - \frac{1}{1-(1-\alpha)(1-q)} < 0$*) than for highly profitable projects.*

When projects are not highly profitable, both the participation and the incentive constraints bind for intermediate collateral qualities. If it were not for incentive problems, borrowers could feasibly promise away more collateral and obtain a larger loan. This would be socially beneficial since capital is productive, but it does not happen because promising away more collateral intensifies banks incentive to deviate and secretly check the value of the collateral. Firms react by seeking smaller loans. In contrast, when projects are more profitable, firms respond not by seeking smaller loans, but by sharing profits. Since banks obtain these profits in all states and not merely when the collateral is found to be good, their incentive to learn the true collateral value prior to lending is diminished as learning would entail a loss of profits whenever collateral is found to be bad.

---

[6] The optimal contract found in Gorton and Ordoñez (2014) emerges in the special case of full information, $\alpha = 0$, and moderately profitable projects, $qA > 1 > q^2A - 1$.

3.3.3. Information and welfare

In this section I examine the effects of information acquisition on welfare. The degree of information, α, is treated as an exogenous parameter. It can be thought of as representing prior knowledge about the collateral; even though agents do not specifically ascertain the collateral quality, the may have other information which leads them to have a more robust estimate of p (i.e. an estimate which is less likely to be revised due to new information). The question I address, then, is the following: If a social planner could affect the degree of information acquisition at the margin, how would it like to do so?

A few observations are required before proceeding to the analysis. Whether banks do acquire information depends on a comparison of their expected profits with and without information acquisition. It is straightforward to verify that information acquisition can only occur when the incentive-compatibility constraint binds, i.e. for intermediate collateral qualities. It is possible to identify the region of p for which information acquisition takes place. For example, when projects are moderately profitable, this region is found by equating profits with and without information acquisition and then solving the quadratic equation $p(qA-1)K^{\star}-\gamma=(qA-1)\frac{\gamma}{(1-\alpha)(1-p)(1-q)}$. We are not particularly interested in the resulting expressions, except perhaps to note that ignorance feeds ignorance: The higher the α, the smaller the region of p for which agents will gather information.

An interesting special case is that of full information, corresponding to the model in Gorton and Ordoñez (2014) except for the inclusion of a participation constraint rather than a zero-profit condition. In the previous section it was shown that there was a discontinuity in the expected use of capital when the incentive-compatibility constraint was binding, depending on the profitability of projects, with highly profitable projects - those for which $q^2A-1>0$ - being less affected by credit constraints than less profitable ones. Highly profitable projects are not unaffected because firm profitability, unlike expected capital usage, is a continuous function of q and A. A sudden drop in expected capital usage can therefore occur if collateral quality declines to such a level that agents find themselves in the information acquisition region.

Figure 3.3 illustrates this. It compares welfare and profits under informed and uninformed for a highly profitable project. If the project were less profitable, profits and welfare would coincide. The vertical difference between the full and dashed lines in region where p is approximately between 0.80 and 0.87 represents the welfare loss due to firms preferring to seek smaller loans as opposed sharing profits when projects are not as profitable. The figure also highlights that the credit constraint begins to bind at a higher collateral quality for less profitable projects.

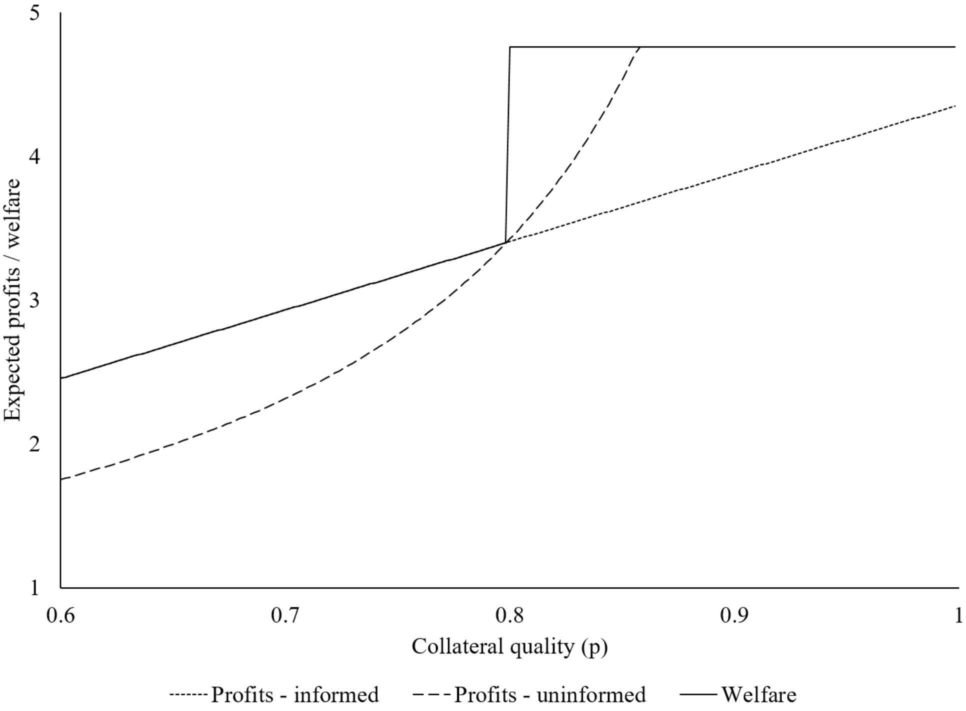

Figure 3.3: Collateral quality, expected profits and welfare in full information case ($\alpha = 0$). The figure shows welfare, and expected profits of firms under informed and uninformed lending respectively. It is based on the case of $q = 0.6$ and $A = 2.8$, implying that projects are highly profitable ($q^2A - 1 = 0.008 > 0$). If projects were slightly less profitable (so that $q^2A - 1 < 0$), welfare would coincide with profits. To the right of approximately $p = 0.87$, welfare and profits under uninformed lending coincide. To the left of approximately $p = 0.80$, welfare and profits under informed lending coincide.

I now consider the case where there is less than full information and examine the impact of changes in α. If p belongs to the region where banks gather information, changing α has no effects on welfare.[7] The more interesting case is therefore that in which p is outside of the information-acquisition region. If information is not acquired, welfare is proportional to the expected use of capital, and there are five possible cases depending on which constraints bind: (1) the participation and collateral constraints bind; (2) the participation and incentive-compatibility constraints bind; (3) the participation constraint bind and the first-best level of capital is feasible; (4) the incentive-compatibility and the collateral constraints bind; and (5) the incentive-compatibility constraint binds and the first-best level of capital is feasible. The parametric constellations corresponding to these case are depicted in Figure 3.2 and described in Proposition 1.

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[7] At the margin, that is. A large increase in α could lead agents outside of the region.

The use of capital specified in the optimal contracts is contingent on no signal being observed, an event that occurs with probability $\underline{p}$. To find the expected value of capital used, we must therefore multiply the capital amount by this probability and then analyze the effects of changing α. The following proposition details how the effects of information acquisition depend on collateral and project quality in the five possible cases discussed above.

Proposition 2. *When the collateral and participation constraints bind simultaneously (case 1), the degree of information acquisition has no effect on welfare. When the incentive-compatibility and participation constraint bind (case 2), more information acquisition is detrimental to welfare. When the incentive-compatibility and the collateral constraints bind (case 4), more information acquisition has negative effects whenever* $p(1-q)C > \gamma$*. Finally, more information acquisition has a positive effect on welfare whenever the capital constraint binds (cases 3 and 5).*

In general, additional information acquisition has two effects. It has the welfare-enhancing effect of decreasing the likelihood of signals: Capital can be employed in more states of the world. On the other hand, if information about collateral quality is widespread, the absence of shocks does not lead to large upward revisions of beliefs about collateral quality. A useful way of thinking about the issue is then to distinguish between collateral quality (values of p) being respectively low (case 1), intermediate (cases 2, 4, and 5), and high (case 3).[8]

The proposition tells us that when collateral quality is low, information acquisition does not affect the expected use of capital as the two effects exactly offset each other. On the other hand, when collateral quality is high, only the first effect is at work. The limiting factor is capital, and more information acquisition makes it more likely that this level of capital is used. There is no countervailing benefit of ignorance as K cannot be increased further.

The more tricky case is that of intermediate levels of collateral quality when incentive problems are present. When projects are moderately profitable, more information always has negative effects. Capital usage is a convex function of p in case 2. This implies that the benefit of an increase from p to $\overline{p}$ more than exceeds the cost of not being able to finance projects in some states. One arrives at a different conclusion when projects are highly profitable. First, for high values of p within the region of a binding incentive-compatibility constraint, the first-best level of capital can be achieved, and in that case more information acquisition always improves welfare. It is therefore only for lower values of p that less information acquisition is potentially helpful.

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[8] This terminology is not entirely accurate. It is, in principle, possible for case 1 to occur for high values of p, for example if C relatively low compared to $K^\star$ in which case it is collateral rather than capital which becomes the limiting factor even for high values of p. I have in mind a situation where C is large relative to $K^\star$ such that the indicated progression between the cases does indeed occur.

Taken together, the results of Propositions 1 and 2 tell us the following: If collateral quality is high, firms can use the optimal level of capital $K^{\star}$. One can think of this as representing the normal state of affairs. When agents are able to fully utilize their technology, more information about collateral values entail a positive externality as agents are less prone to be affected by shocks. If collateral quality deteriorates somewhat, however, agents with moderately profitable projects face credit constraints. They can suddenly face a sharp decline in the amount of capital to which they have access, a situation resembling a panic, and are using less capital than is feasible given the technology available to them. Moreover, when these constraints are present, the return to using more capital is an increasing and convex function of p (recall that $K = \frac{\gamma}{(1-\alpha)(1-p)(1-q)}$). While greater ignorance increases risks or fragility, it also allows firms to use more capital when no signals are observed, and the ability to use more capital in some cases is so valuable that it outweighs the additional risk.

Finally, I note that the finding that ignorance is beneficial when credit constraints bind is robust to alternative formulations of the model. In general, any formulation which emphasizes uncertainty about p will favor such uncertainty in the credit constraint region because capital usage is convex within that region, but not elsewhere. One could also have modeled the externality by linking information gathering and the information cost. Information might leak, for example. If a bank invests heavily in information and develop expertise in valuing collateral, rival banks may benefit as employees change jobs and use their expertise. A natural formulation of this idea would be let the information cost, γ, be a decreasing function of the degree of information acquisition, $1-\alpha$. Since $K = \frac{\gamma}{(1-p)(1-q)}$ in the credit constraint region, it would be welfare-improving to reduce information acquisition in order to increase information costs.

3.4. Central Bank Collateral Policy

The considerations of the previous section show that there is a potential role for a social planner in trying to coax banks towards becoming more or less informed depending on the circumstances. We saw that information production entails a positive externality when the first-best level of capital is feasible and a negative externality when credit constraints bind. At the margin, a central bank might therefore attempt to induce agents to produce more or less information depending on the state facing agents. That may be an adequate description of a central bank's influence in the sense that many factors outside a central bank's influence affect the incentives to produce information. In this section, however, I consider the starker case in which α is endogenous.

I focus attention on the more interesting case which is when uninformed lending dominates informed lending and projects are not highly profitable, corresponding to cases 2 and 3. In this case, welfare is increasing for α as long as the credit constraint binds. At some point, however, $\frac{\gamma}{(1-\alpha)(1-p)(1-q)}$ will exceed $K^{\star}$ and at that point expected capital usage begins to decline as a function of α.[9]

The degree of information acquisition, α, is now defined as the fraction of banks gathering information about collateral. A central bank attempts to control the degree of information acquisition through collateral policy. Specifically, it is assumed that banks' occasionally face payment shocks of magnitude M which either require them to hold ample "reserves", i.e. capital (numeraire) not passed on to firms ($\overline{K} - K$), or to use their secured loans as collateral with the central bank. Capital is thus both an input of production and a means a payment. Banks are assumed never to want to default, and so will either retain enough capital or be sure that they have access to it via the central bank.

The assumption that banks sometimes have to borrow from the central bank, or alternatively must hoard liquidity, has a counterpart in reality. Since the advent of real-time gross settlement systems for settling interbank payments, banks frequently face substantial intraday payment imbalances, and there generally is not a functioning intraday money market. Because the timing of payments is uncertain, intraday liquidity shocks are sometimes viewed as being uninsurable in the money market (Martin, 2004), and major central banks commonly offer credit at zero interest rates against collateral during the day.[10] Of course, the assumption that banks occasionally need to resort to central bank borrowing could be justified on other grounds such as imperfections in the money market.

The central bank's objective is to maximize the aggregate profits of firms.[11] If a fraction $1-\alpha$ of banks gather information, aggregative profits are:

$$(1-\alpha)\left[p(qA-1)K^{\star}-\gamma\right]+\alpha\underline{p}(qA-1)K(p,\alpha) \tag{18}$$

where $K(p,\alpha) = min\left\{\frac{\gamma}{(1-\alpha)(1-p)(1-q)}, K^{\star}\right\}$.

The central bank sets haircuts, $h(p|\hat{\alpha})$, that depend on collateral quality and a target level of information acquisition, $\hat{\alpha}$. Specifically, it requires banks verify to the collateral quality with probability $1-\hat{\alpha}$ in order to qualify for their collateral to be eligible. This is obviously an abstraction. It is intended to capture the idea of choosing a random sample of loans for audit. In reality, eligible central bank collateral is often a securitized product such as a mortgage-backed security representing a pool of loans. To ascertain the quality of the collateral, one can think of the model as saying that the bank must choose a sample of a certain size which is to be analyzed in detail and disclose the information of the detailed investigation.[12]

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[9] Parametrically, we are guaranteed to be in the "uninformed" region whenever p exceeds the larger of the two solutions to the quadratic equation $\frac{\gamma}{(1-p)(1-q)} = p(qA-1)K^{\star}-\gamma$. The requirement that projects not be highly profitable in the region with credit constraints is that $qA - \frac{1}{1-(1-\alpha)(1-q)} < 0$ whenever α is less than the α which solves the equation $\frac{\gamma}{(1-\alpha)(1-p)(1-q)} = K^{\star}$.

[10] The aim of having real-time settlement systems and interest-free, collateralized intraday credit is to ensure the smooth functioning of payment systems. That this structure provides a stronger role for central bank collateral policy can be viewed as an unintended consequence.

[11] Recall that the participation constraint binds given our parametric assumptions; all of the surplus that is generated therefore accrues to firms.

If the collateralized loan is eligible as central bank collateral, the bank can make payment whenever $\overline{K} - K + V(1-h(p|\hat{\alpha})) \geq M$, where V denotes the central bank's valuation of the asset posted as collateral. I assume that the central bank values the loan as: $V = K$. This is a natural assumption because, in the case I focus on, banks break-even in expectation and are on average repaid K. The constraint facing banks then reads:

$$\overline{K} - h(p|\hat{\alpha})K \geq M \tag{19}$$

By assumption we are in the region where banks, left to their own devices, would not gather information. Now, the central bank initially announces that it wants banks to verify the collateral quality of firms with probability $1-\hat{\alpha}$ in order to qualify for central bank eligibility. For this to be an equilibrium outcome, it must then be the case that firms, taking $\hat{\alpha}$ as given are better off under an eligible contract than one which is not.[13] Concretely, this means that the central bank must be able to choose a haircut such that those pairs chosen for audit would not be better off not borrowing from the central bank. The harshest "punishment" the central bank can inflict is to refuse an asset as collateral, i.e. imposing a 100% haircut, in which case the maximal capital use is $\overline{K} - M$. The requirement is therefore:

$$\underline{p}(qA-1)\left(\overline{K} - M\right) \leq p(qA-1)K^{\star} - \gamma \tag{20}$$

We are now in a position to define an equilibrium.

Definition 1. *An equilibrium is a pair of optimal contracts* (K, R, x)*, one for informed and one for uninformed lending as defined in Lemma 1 and Proposition 1 respectively, with the constraint* $K \leq K^{\star}$ *(6) replaced by* $K \leq min\left\{K^{\star},\ \frac{\overline{K}-M}{h(p|\hat{\alpha})}\right\}$*. Firms choose the profit-maximizing contract, and*

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[12] For a real-life example, in 2011 the Danish central bank permitted banks to post portfolio of loans as collateral, but required that these portfolios were audited to ensure that the loan quality met certain quality standards.

[13] To rule out that firms chosen for audit seek financing elsewhere, one can think of the central bank as pre-selecting a fraction $1-\hat{\alpha}$ of firms for audit and requiring banks to perform the audit if they happen to be matched with either of these firms.

the central bank selects of a fraction, $\hat{\alpha}$, of loans for which banks must acquire information with the objective of maximizing aggregate profits as defined in (18) subject to the feasibility condition given by (20).

The timing assumption is that central bank policy is known at the beginning of the period, while firms and banks are assumed to take the central bank's target $\hat{\alpha}$ as given when making choices. The only other "reasonable" choice would be $\alpha = 1$ since agents are identical and are all in the uninformed region. However, the higher the α, the easier it is for the central bank to choose a haircut satisfying the feasibility constraint in (20). If agents were to take $\alpha = 1$ as given, the central bank would be even less constrained in its ability to attain its target.

3.4.1. Optimal collateral policy

A few initial observations are helpful when trying to understand collateral policy. First, the optimal haircut level is not unique. The central bank either wants a bank to gather information or it does not, and the only question is whether there exists a sufficiently large haircut to induce information acquisition. One can therefore restrict attention to haircuts of 0% and 100%. The description, incidentally, is consistent with actual collateral policy. Central banks typically set low haircuts for a narrow set of eligible assets while entirely excluding others. Second, the results from Section 3.3 can readily be applied without having to re-solve the problem: If the central bank does not accept a loan as collateral, the new constraint $K \leq \overline{K} - M$ is, from a mathematical point of view, completely analogous to the constraint $K \leq K^{\star}$ and so simply replaces it whenever $\overline{K} - M \leq K^{\star}$. Third, we can either think of a certain fraction $\hat{\alpha}$ as having been pre-selected for audit or assume that a random audit taking place immediately after the contracting stage with identical results. In the latter case, firms would be comparing profits under information-based lending $E[\Pi]_I$ with profits under the random audit which would be $\hat{\alpha} E[\Pi]_I + (1 - \hat{\alpha}) E[\Pi]_{UI}$, and that clearly results in exactly the same contract choices.

Observe also that the central bank will never want to target an $\hat{\alpha}$ s.th. $K(p, \hat{\alpha})$ is in the credit constraint region (i.e. where $K(p, \hat{\alpha}) = \frac{\gamma}{(1-\hat{\alpha})(1-p)(1-q)}$). The objective function is increasing in that region because $\underline{p}(qA - 1)K(p, \alpha)$ is increasing in α by Proposition 2 and is larger than the payoff from uninformed lending, $p(qA - 1)K^{\star} - \gamma$. Therefore, we can conclude that an optimal degree of information acquisition must be such that $K(p, \hat{\alpha}) = K^{\star}$. Second, once the first-best level of capital is reached, the expected use of capital is declining so there is potentially scope for an "active", i.e. information-inducing, collateral policy.

An illustration of situation from the perspective of a firm is provided in Figure 3.4. The figure shows the expected profits of firms with and without information acquisition for different values of p, in the latter case for different values of α (0.2 and 0.5 respectively). As α increases, the firm (which takes α as given) finds it less attractive to choose a contract which entails information acquisition. When p is in the region with credit constraints, the firm benefits from ignorance as credit constraints are weakened. Agents with higher quality collateral, however, find their profits reduced when ignorance is more widespread.

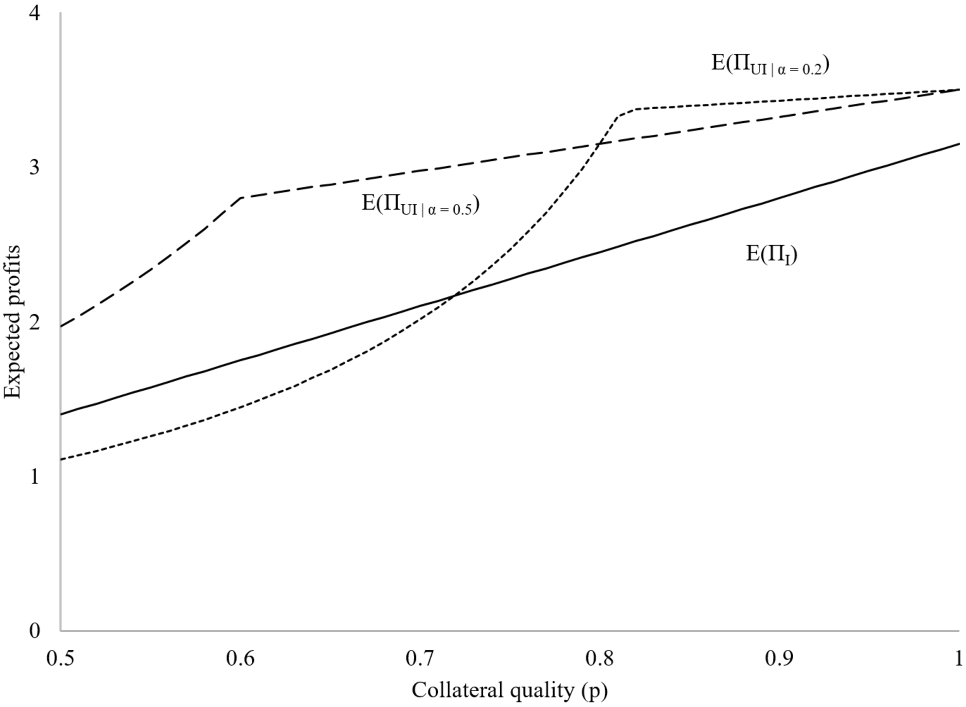

Figure 3.4: Collateral quality and expected profits. The figure depicts how expected firm profits vary with collateral quality depending on whether banks acquire information or not. The sold line shows profits when information is acquired. The two dashed lines show profits when information is not being acquired when α, the degree of information acquisition in the economy, is respectively 0.2 (corresponding to more information acquisition) and 0.5 (corresponding to less information acquisition).

An alternative perspective is provided by fixing collateral quality and varying the degree of information acquisition (treating it as exogenous to the choice of an individual bank). Figure 3.5 shows the effects of more ignorance (higher α) for different levels of collateral quality. When collateral quality is high, specifically so high that $K(p, \alpha) = K^{\star}$ is feasible for any α, more ignorance is always harmful. On the other hand, some ignorance is beneficial when collateral quality is lower. The flat portions of the lines correspond to the region in which a bank will want to acquire information and is therefore unaffected by the level of ignorance. At some α it becomes optimal for a bank not to gather information and lend uninformed. In that region the credit constraint binds, and expected profits are increasing. When the credit constraint no longer binds, however, ignorance only increases risks and becomes detrimental.

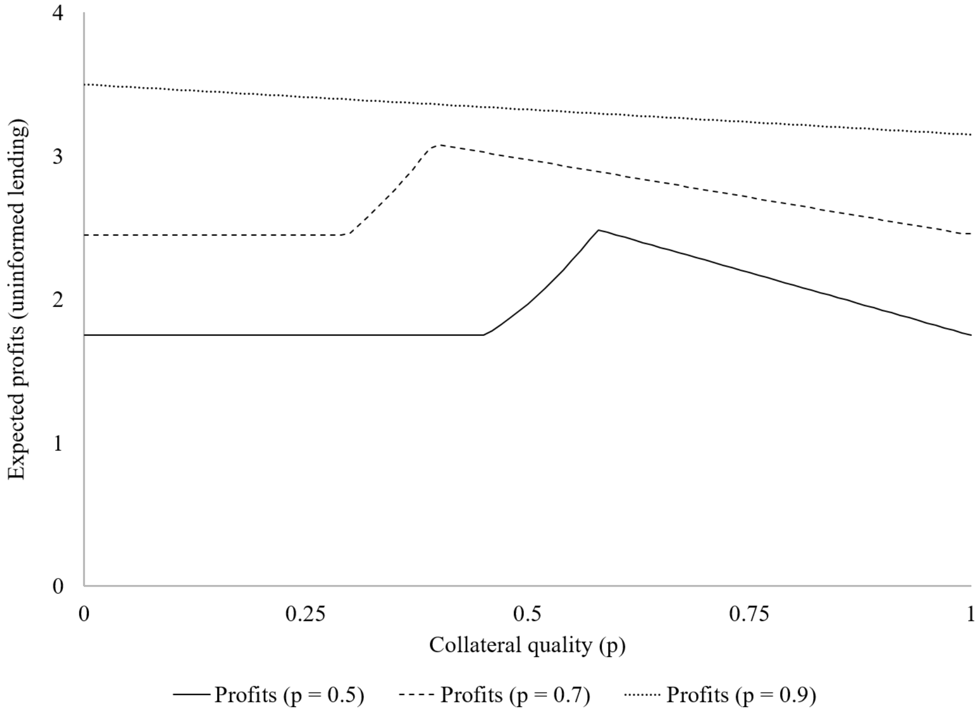

Figure 3.5: Ignorance and expected profits. The figure shows expected profits as a function of α for three different values of collateral quality: $p = 0.6$, $p = 0.8$, and $p = 0.9$. α is the degree of information acquisition in the economy, with higher values of α correspond to less information acquisition. The flat parts of the lower two lines correspond to regions in which banks acquire information, the increasing parts to regions when the credit constraint binds, and the decreasing parts to regions in which the first-best level of capital is attainable. When collateral quality is adequately high, as illustrated with the top line, the first-best level of capital is always attainable, and profits are everywhere a decreasing function of α.

To identify an optimal collateral policy, one must first ask whether the central bank is even able to induce some measure of information acquisition on the part of agents. As noted, the strictest requirement a central bank can impose is a haircut of 100 percent in which case $K \leq \overline{K} - M$ and comparing profits under this restriction with profits under informed lending leads to the central bank's feasibility constraint in (20). We can solve that for α to find:

$$\alpha \geq \alpha_{feas} = \frac{1}{1-p}\left(1 - \frac{pK^\star - \frac{\gamma}{qA-1}}{\overline{K} - M}\right) \tag{21}$$

Whenever $\alpha_{feas} > 1$, no information inducing collateral policy is possible. The condition for the central bank to be able to affect the information acquisition at least somewhat is therefore as given in Lemma 2.

Lemma 2. *A central bank can use collateral policy to induce information acquisition provided that*

$$\overline{K} - K^\star \leq M - \frac{\gamma}{p(qA-1)} \tag{22}$$

The above result tells us that central banks have more influence when payment flows are large, or at least when agents cannot easily obtain liquidity from other sources such as the money market.

One can interpret $\overline{K} - K^{\star}$ as reserves with the central bank as these are funds, which the bank cannot lend.[14] An implication of the model is therefore that if $\overline{K}$ is large, central bank collateral policy becomes impotent. Thus, other central bank policies such as large-scale asset purchases, which increase aggregate reserves, limit the potency of collateral policy.[15]

If the central bank can induce information acquisition, the next question is what degree of information acquisition it should target. First, one can proceed by first identifying the unconstrained optimal α. Maximizing the objective function w.r.t. α produces:

$$\alpha_{opt} = \frac{1}{2} + \frac{\gamma}{2(1-p)(qA-1)K^{\star}} \tag{23}$$

In order for an active collateral policy to make sense, it must be the case that $\alpha_{opt} < 1$, which implies $\gamma < (1-p)(qA-1)K^{\star}$. This tells us that collateral policy is a more attractive tool when the cost of information is low relative to the marginal payoff from being able to use extra capital in expectation.

However, a further factor must also be taken into consideration. For any α to be optimal, it must be the case that $K(p,\alpha) = K^{\star}$. This means that any target α must exceed the following:

$$\alpha_{min} = 1 - \frac{\gamma}{(1-p)(1-q)K^{\star}} \tag{24}$$

Taken together, the above observations imply the following: Ideally, the central bank would like to choose $\hat{\alpha} = \alpha_{opt}$, provided that this quantity is less than one; otherwise there is no scope for collateral policy. The central bank may, however, be constrained by any $\hat{\alpha}$ having to exceed both α_{min} and α_{feas}. If $\alpha_{opt} < 1$, welfare is decreasing in α in the region $[\alpha_{opt},\ 1]$, and the optimal choice is therefore to choose the smallest possible $\hat{\alpha}$ which must therefore equal $max\left\{\alpha_{min}, \alpha_{feas}, \alpha_{opt}\right\}$. This finding is summarized in Proposition 3.

Proposition 3. *An optimal collateral policy entails inducing information acquisition on the part of a fraction* $1 - \hat{\alpha}$ *of agents, with* $\hat{\alpha}$ *given by:*

$$\hat{\alpha} = min\left\{max\left\{\alpha_{min}, \alpha_{feas}, \alpha_{opt}\right\},\ 1\right\} \tag{25}$$

---

[14] In aggregate, bank reserves with the central are primarily determined by central bank actions and do not reflect the lending decisions on the part of banks, as explained in e.g. Keister and McAndrews (2009), contrary to the common conception that banks are sometimes "sitting" on reserves.

[15] As an aside, there are other, positive side effects of such policies. An interesting example is provided by Bech et al. (2012) who show that payment systems started functioning more smoothly in the US following the introduction of emergency liquidity measures because, with reserves being ample, banks' opportunity cost of holding these reserves became very small.

with α_{min}, α_{feas} and α_{opt} defined in (24), (21), and (23) respectively.

Since agents, left to their own devices, would all lend uninformed, an immediate corollary is that a central bank generally wants more information than is privately produced when p is relatively high. The opposite may be the case when p is low enough for agents to be in the information-acquisition region for some α, as will be discussed in the following section.

The model can also be applied to thinking about the characteristics of the assets which central banks prefer as collateral. As we are concerned with situations in which a central bank may want to induce information acquisition by refusing to accept certain assets as collateral, a natural way to address this issue is to identify the assets for which the cost of inducing information acquisition is the lowest. If more information acquisition is desirable, then the central bank should leave these assets out of the set of eligible assets to induce information acquisition in the cheapest possible way.

We must first define what is meant by the cost of a given collateral policy. I focus on the difference in profits with and without information acquisition: $E[\Pi_I - \Pi_{UI}] = (p(qA-1)K^\star - \gamma) - \underline{p}(qA-1)K(p,\alpha)$. A "high" cost then corresponds to a large negative value. This is the loss to those agents who are forced to gather information when they would have preferred not to. One could imagine an extension of the model in which agents were heterogeneous along some dimensions, in which the central bank first should attempt to induce information acquisition in the lower cost cases. Since central banks will only induce information acquisition when $K(p,\alpha) = K^\star$, the cost can be expressed as:

$$E[\Pi_I - \Pi_{UI}] = -(1-\alpha)(1-p)(qA-1)K^\star - \gamma \tag{26}$$

Now, if there were heterogeneity, it might also be the case that $K(p,\alpha) = \frac{\gamma}{(1-\alpha)(1-p)(1-q)}$ for some assets. For these, the cost would be:

$$(qA-1)\left(pK^\star - \frac{\gamma}{(1-\overline{p})(1-q)}\right) - \gamma \tag{27}$$

Two implications follow in Proposition 4:

Proposition 4. *A central bank prefers collateral characterized by high information costs. The central bank gives the most preferential treatment to the highest quality (p) assets for which the credit constraint still binds.*

It is straightforward to see that the cost of an active collateral policy is higher if γ is large.

One can think of the model as one of asymmetric information. If information costs are high, banks have less incentive to exploit their potential informational advantage. Effectively, there is less asymmetric information. One can think of high information cost assets as being information-insensitive (Gorton and Ordoñez, 2014; Dang et al., 2015). Under that interpretation it makes sense to equate high information cost asset with e.g. safe debt securities as these are among the securities least plagued by informational asymmetries. Such an interpretation is consistent with the behavior of central banks who tend prefer highly liquid debt securities.[16]

The second statement in Proposition 4 follows from the fact that cost is decreasing (i.e. less negative) in p whenever $K(p, \alpha) = K^{\star}$ and increasing whenever $K(p, \alpha) = \frac{\gamma}{(1-\alpha)(1-p)(1-q)}$. Collateral just on the border of being credit constrained rather than the very best collateral should therefore receive the most preferential treatment.

Project quality also matters for collateral quality and mostly, at least as long as p is fairly large (and always when $K(p, \alpha) = K^{\star}$), such that loans involving higher quality projects are preferred as collateral. The logic is that agents who prefer not to acquire information can, in expectation, use more capital when information is not acquired. Since welfare is proportional to both the amount of capital and its profitability, it is preferable that agents with higher quality capital do not gather information.

3.4.2. Informed lending and panics

In the preceding, it was assumed that p was in the region with no information acquisition. Suppose instead that p is such that agents would gather information assuming other agents also gathered information. In that case the economy might be "stuck" in an undesirable full information equilibrium with welfare equaling $p(qA - 1)K^{\star} - \gamma$. On the other hand, if each agent believed that no other agent would gather information, there would be no credit constraint, and welfare would be $p(qA - 1)K^{\star}$, an improvement over the case with full information. This highlights the possibility of multiple equilibria depending on beliefs and that there can be too much information acquisition when collateral quality is low.

It is outside the scope of the model to say how agents might form their beliefs, but it is possible to say something about whether a particular equilibrium is more or less "likely" in the sense of occurring for a wider range beliefs. There must exist some α above which agents no longer find it optimal to gather information. Since information-acquisition can only ever be optimal when the incentive-compatibility constraint binds, this threshold value of α is defined setting profits equal under informed lending and uninformed when this constraint binds, i.e.:

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[16] Central banks also tend to give preference to traded over non-traded assets which likely also reflects concerns about asymmetric information. As an example, the ECB has much stricter collateral requirements when "non-marketable" assets are used as collateral. Of course, central banks may also be wary of accepting assets plagued by asymmetric information because of lemons problems. There is empirical evidence to suggest that banks do, in fact, post their worst collateral with central banks, see Fecht et al. (2015).

$$p(qA-1)K^{\star}-\gamma=(qA-1)\frac{\gamma}{(1-\overline{p})(1-q)} \tag{28}$$

The right-hand side of expression is increasing in α, as $\overline{p}$ is an increasing function of α, and tends to infinity as α approaches one. It follows that there is a unique α for which that expression is equal to the left-hand side of the above equation. This indirectly defines a threshold value of α below which an agent would want to gather information.

One can then derive comparative statics results by implicit differentiation. The key findings are provided in Proposition 5.

Proposition 5. *Assume p is such that banks would acquire information if other banks did as well. In that case there exists a unique threshold value of α such that a bank will gather information if it believes that a fraction $1-\alpha$ or more of other banks also gather information. This threshold is increasing in project quality (A) and the first-best level of capital ($K^{\star}$) and decreasing in information costs (γ) and collateral quality (p). Welfare is higher if no banks gather information than if all banks gather information.*

The above suggests that banks might collectively "panic", for instance because of a deterioration in collateral quality, and decide to gather information, leading to a sharp contraction in credit. One can think of multiple real-life situations resembling such a panic. For example, a drop in house prices might lead banks to evaluate housing collateral more critically and tighten lending standards, leading to less credit (and there may be a feedback loop as house prices drop further, exacerbating the riskiness of the collateral). It also highlights the role of beliefs. Some types of funding are based on trust rather than thorough analysis: It is difficult to ascertain, for example, whether a bank or a sovereign is really solvent, and it may be optimal for one agent to withdraw funding simply because the agent believes that other agents are likely to do the same. In that sense, sudden information production can be interpreted as a run-like phenomenon.

A central bank will want to halt run-like behavior, and one could imagine it using collateral policy to counter sudden information production. To engineer a move away from information production, a literal interpretation of the model might be that it should worsen the terms for collateral known to be good, thus making information acquisition less attractive. More realistically, though, banks are likely in general need of liquidity in a panic-like situation, and the best response of the central bank could be to provide especially favorable terms for collateral of lower quality.

Since many central banks normally only accept a narrow set of assets a eligible collateral, their extensions of the set of eligible collateral to include more assets can also be viewed as making low quality collateral more attractive in relative terms.

A concrete way of modeling a "panic" might be to assume that an aggregate shock has occurred. An aggregate shock, following Gorton and Ordoñez (2014), is defined as an event which transforms fraction $(1-\eta)$ of good collateral into bad collateral. One might then use the model to consider the following hypothetical: Suppose a crisis (an aggregate shock) is believed to be imminent, with everyone sharing the belief that others will begin producing information upon the occurrence of a shock. Would welfare then be higher if agents had acquired full knowledge in advance of the crisis, or would they be better off acquiring information once the crisis occurs? Proposition 6 suggests that more information is generally associated with a more robust economy.

Proposition 6. *Faced with an aggregate shock that is sufficiently large to induce information acquisition, welfare is larger if information has been acquired in advance of shocks, except for the region of aggregate shocks* (η) *satisfying* $\frac{\gamma}{qA-1} \geq \eta K^{\star} - \frac{\gamma}{(1-\eta)(1-q)} \geq 0$.

This result tells us that, in many cases, having information makes agents more robust to shock. This is reminiscent of the findings from the dynamic version of Gorton and Ordoñez (2014) who find that less information acquisition is generally associated with larger effects of shocks.

3.5. Extensions

In this section I consider some extensions to the model. In the preceding, the central bank would induce information acquisition by restricting the amount of capital available for lending. If loan capital were scarce, however, it seems plausible that bargaining power might shift from firms to banks. In the following section I examine the consequences of letting banks rather firms dictate loan terms and show that a shift in bargaining power does not alter the conclusions of the previous section.

The introduction of the information externality in the static setting can be viewed as a means capturing a trade-off where uninformed lending allows agents to use more capital at the expense of fragility. In another extension I consider a dynamic version of the model where the central bank's options are more limited: If it is to induce information acquisition, it cannot select a fraction of agents, but must force all uninformed agents to gather information. Finally, another externality arises in a dynamic (OLG) setting because agents do not internalize the future effects of their information choices. A social planner will generally want more information than is produced, and I discuss how collateral policy can be used to reach the social optimum.

3.5.1. Bargaining power with banks

Earlier we saw that central banks only use collateral policy to actively encourage information acquisition when the first-best level of capital, $K^\star$, is feasible, i.e. when p is large and $K^\star < \frac{\gamma}{(1-\alpha)(1-p)(1-q)}$. To show that shifting bargaining power from firms to banks does not alter earlier conclusions about collateral policy, two shortcuts are helpful in simplifying exposition. First, since p is large, the collateral constraint can be ignored. Second, I consider only the case where incentive-problems are the most pronounced, which is when $\alpha = 0$.

Now, suppose that banks have all of the bargaining power. With uninformed lending their problem is to choose K and R in order to maximize their payoff R subject to a participation constraint on the part of firms and an incentive-compatibility constraint on their own part. When $\alpha = 0$, these constraints become:

$$qAK - R \geq 0 \tag{29}$$

$$qR - K + \frac{\gamma}{1-p} \geq 0 \tag{30}$$

Together, these constraints imply that:

$$qAK \geq R \geq \frac{1}{q}\left(K - \frac{\gamma}{1-p}\right) \tag{31}$$

Whenever projects are highly profitable ($q^2A - 1 \geq 0$) the expression to the left exceeds that to the right, and bank profits are therefore maximized by choosing K as large as possible and setting $R = qAK$. Consider on the other hand somewhat profitable projects for which ($q^2A - 1 < 0$). In order for uninformed lending to be feasible, it follows from (31) that the use of capital can be at most $K \leq \frac{\gamma}{(1-p)(1-q^2A)}$, and - if K could be chosen freely - the profit-maximizing choice would be to choose exactly $K \leq \frac{\gamma}{(1-p)(1-q^2A)}$ and $R = qAK$. However, capital is restricted to be less than $\overline{K} - M$ when central banks refuse assets as collateral, and this constraint can only have an effect if $\overline{K} - M < K^\star$. We observed earlier that $K^\star < \frac{\gamma}{(1-p)(1-q)}$ and clearly $\frac{\gamma}{(1-p)(1-q)} \leq \frac{\gamma}{(1-p)(1-q^2A)}$. It follows that the optimal choice is again to choose the largest possible K which in this case is $\overline{K} - M$ (and firms' participation constraint will again bind).

These considerations imply that bank profits under uninformed lending are $(qA - 1)(\overline{K} - M)$. With informed lending, the bank would earn $p(qA - 1)K^\star - \gamma$. Hence, the central bank would be able to induce information acquisition whenever:

$$p(qA - 1)K^\star - \gamma \geq (qA - 1)(\overline{K} - M) \tag{32}$$

But the above feasibility condition is exactly identical to the condition found when firms have all of the bargaining power, see Lemma 2. It therefore follows that changing assumptions about bargaining power neither affects welfare, since the amount of capital used is the same, nor the ability of central banks to affect outcomes; it only changes the distribution of profits.

3.5.2. Dynamics with information externality

In this section I consider the implications for collateral policy when the central bank's options are more limited: It cannot require a fraction of banks to gather information, but must either require all or none of the uninformed to gather information. The purpose of this section is therefore to function as a sort of robustness check. I use the dynamic, overlapping generations model found in Gorton and Ordoñez (2014) in which the static setting is repeated period after period. What changes over time is the distribution of knowledge about collateral quality.

Initially, there is assumed to be full knowledge of collateral quality, but in each period some knowledge is lost. Specifically, information decays in such a way that each period a fraction λ of agents lose knowledge of whether their collateral is good or bad. If no information is being reacquired - and whether information is reacquired will depend on p and α - the collateral is perceived to be of average quality. With reacquisition of information each period, the level of consumption is constant through time as there is always full knowledge. Without reacquisition of information and starting from a state of full knowledge, the distribution of probabilities therefore evolves as $f(1) = p(1-\lambda)^t$, $f(p) = 1-(1-\lambda)^t$and $f(0) = (1-p)(1-\lambda)^t$. For further details about the dynamic model, see Gorton and Ordoñez (2014). Finally, I assume that informational shocks which affect uninformed agents of one generation are not known to future generations so only the measure of informed agents evolves through time.

When information evolves through time, one can also think about the evolution of credit and beliefs. Consider starting from a case of full information ($\alpha = 0$). If p is in the information-acquisition region, it always stays there as information is continually reacquired. If, on the other hand, p is outside that region, information will gradually decay, and credit constraints must at some point vanish, as $\frac{\gamma}{(1-\alpha)(1-p)(1-q)}$ will eventually exceed $K^\star$. From such a point onwards, however, the effects of agents becoming less and less uninformed are negative as signals become more and more likely to be observed.

It might seem that policy of inducing information acquisition for all agents should never be optimal in this setting. After all, uninformed agents use more capital in expectation than informed ones. However, along the path from being fully informed to less informed there is a period in which more capital is used. One could therefore pose the question of whether there is what essentially amounts to a stopping time, a point at which the central bank should enforce a strict collateral policy. The determinants of that stopping time could then be viewed as the factors influencing the strictness of collateral policy. It turns out that rephrasing the problem in these terms leads to essentially the same qualitative conclusions as detailed in Proposition 7.

Proposition 7. *In a dynamic setting in which the central bank can only force all banks to gather information simultaneously, it will enforce a policy which induces information acquisition sooner when (a) information costs are low, (b) information decays slowly, (c) collateral quality is relatively low, and (d) projects are more profitable.*

These findings are essentially identical to those in Proposition 3, only with the difference that said result describes an optimal information level whereas this proposition describes whether a central bank should tighten sooner rather than later. In their own way, both therefore describe the factors that enter into thinking about the "leniency" of collateral policy. It is also straightforward to find an unconstrained optimal α in a dynamic setting. Suppose that an information level $(1-\alpha)$ is to be maintained, and let $V(\alpha)$ be the value function associated with maintaining that information level. Then $V(\alpha)$ is described by:

$$V(\alpha) = \alpha \underline{p}(qA-1)K^\star + (1-\alpha)(qA-1)pK^\star - (1-\alpha)\lambda\gamma + \beta V(\alpha) \tag{33}$$

It follows that:

$$V'(\alpha_{opt}) = 0 \Rightarrow \alpha_{opt} = \frac{1}{2} + \frac{\lambda\gamma}{2(1-p)(qA-1)K^\star} \tag{34}$$

This is the same as in the static case, only with lower information costs, $\lambda\gamma$ rather than γ. Now, the above takes as given a situation in which agents are uninformed and p is such that agents will not reacquire information on their own. An alternative is that p belongs to the region where information is being reacquired each period. In that case there is perfect information each period, and the per period welfare is $p(qA-1)K^\star - \lambda\gamma$. Agents would collectively be better off in the long term if there information were not reacquired, and more agents decided to lend uninformed.

3.5.3. Dynamics without information externality

The dynamic model in Gorton and Ordoñez (2014) also features an externality of its own. The overlapping-generations framework effectively makes agents impatient relative to a social planner as agents do not take into account the effect of their actions on all future generations. In essence, where a bank's calculation involves comparing whether the gain from gathering information exceeds the cost of doing so, the social planner consider all discounted future gains. A simple way of showing this is as follows: Let $\Delta\pi$ denote the one-period difference in profits between gathering and not gathering information (exclusive of the information cost). With probability λ, the gain from information gathering lasts for one period and is $\Delta\pi$, with probability $\lambda(1-\lambda)$ the gain lasts for two periods and is $\Delta\pi + \beta\Delta\pi$, and so forth. It is then straightforward to that the expected discounted value of future gains exceed the cost when:

$$\Delta\pi \geq \gamma(1-\beta(1-\lambda)) \tag{35}$$

It follows that a social planner effectively faces a lower information cost than banks and therefore wants information production for a wider range of collateral values than is being produced. Gorton and Ordoñez suggest the use of lump sum taxes on individuals. Here I describe how central bank collateral policy can achieve the social optimum.

The need for intervention arises because of the difference in information costs facing agents and a social planner, who takes into account the future. A social planner would want information production whenever[17]:

$$(1-\beta(1-\lambda))\frac{\gamma}{qA-1} \leq pK^{\star} - K(p) \tag{36}$$

whereas banks produce information when:

$$\frac{\gamma}{qA-1} \leq pK^{\star} - K(p) \tag{37}$$

The right-hand sides of the above inequalities are only positive in the region where the incentive-compatibility constraint binds, i.e. when $K(p) = \frac{\gamma}{(1-p)(1-q)}$. Hence, a collateral policy that aims at changing incentives for information gathering will only affect that region. In order to implement the collateral policy, the central bank must apply the following the logic. Uninformed lending is preferred to informed lending whenever:

$$p(qA-1)K^{\star} - \gamma \leq (qA-1)K \tag{38}$$

Hence, the smallest K for which uninformed lending could still be an outcome is $pK^{\star} - \frac{\gamma}{qA-1}$. In order to prevent an agent from borrowing more than K, the central bank must set a haircut s.th. $\overline{K} - h(p)K < M$. It follows that a haircut policy must satisfy the following requirement:

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[17] See Proposition 7 in Gorton and Ordoñez (2014). Note a minor difference in notation, though. What they call λ, I call $1-\lambda$.

$$h(p) > \frac{\overline{K} - M}{pK^{\star} - \frac{\gamma}{qA-1}} \tag{39}$$

An haircut of at least this magnitude must therefore be applied to all collateral which supports uninformed lending and has p satisfies equation (36).

The above, to summarize, describes the collateral for which the central bank will want information acquisition. This is the lowest quality collateral for which information acquisition does not already take place. It then sets haircuts based on the following logic. It first calculates the lowest level of capital for which an agent would prefer uninformed to informed lending. Having found this level of capital, it then asks which haircut is sufficient to ensure that agents prefer informed to uninformed lending. Of course, since haircuts cannot exceed 100 percent a particular haircut policy may not be feasible, as also discussed in Lemma 2. A corollary is also a lower haircut suffices for a larger p.

Finally, we can consider some effects of a stricter collateral policy as relates to aggregate shocks. Recall from earlier that we defined an aggregate shock as on that transformed a fraction $(1-\eta)$ of good collateral into bad collateral. Now, the analysis in the static setting suggested the benefits of pursuing a more lenient collateral policy when agents were credit constrained. However, the following proposition suggests that such leniency may slow down a recovery.

Proposition 8. *If p is such that $K(p) = K^{\star}$ and a sufficiently large aggregate shock occurs, then an optimal collateral policy results in a faster recovery than would a more lenient collateral policy.*

The analysis in the static setting implied that central banks should attempt to support uninformed lending when collateral quality declines, but the preceding suggests that there may be costs associated with such a policy.

3.6. Conclusion

This paper examines a model of collateralized lending and central bank collateral policy. Borrowers have unpledgeable income, but can nevertheless secure credit because of access to collateral. The key friction in the model is that lenders have an informational advantage in valuing collateral. They can, at a cost, verify the true value of the collateral and only lend when the collateral is good. If there were no incentive problems, uninformed lending - lending based solely on the expected value of the collateral - would always dominate informed lending. Lenders, however, have strong incentives to learn collateral quality prior to lending. To avoid this, borrowers may prefer to obtain smaller loans. They are, in a sense, credit constrained. An interesting outcome of the model is that credit constraints afflict lower quality projects more, even though project and collateral quality are unrelated.

A central bank is introduced in the second part of the paper. It attempts to affect agents' incentives to produce information. Actual central banks have on more occasions made e.g. disclosure requirements about risks a prerequisite for eligibility of assets with the central bank. This feature is reproduced in the model as the central bank attempts to induce information acquisition on the part of banks to limit the risk of shocks as long as collateral is perceived to be of relatively high quality. If a collateral crisis materializes, however, the central bank reverts course and attempts to support uninformed lending. Thus, the model may help explain features of actual collateral policy such as the use of narrow and broad sets of collateral with the latter only being introduced in times of crisis.

At a more general level, the model points to a link between two seemingly disparate activities of banks, their lending or investment decisions and their role as providers of payment services, through central bank collateral policy. In the terminology of Chapman et al. (2011), the paper considers the "payments-system liquidity channel" of collateral policy. In reality, policy operates through other channels as well, for example by affecting liquidity and risk-taking incentives. If central banks set low haircuts on assets, those assets may become more liquid which in turn affects asset allocation decisions, while inadequate haircuts may also produce moral hazard problems.

The key elements of the model can be thought of as a stylized description of e.g. an individual or a firm applying for a loan using real estate as collateral. Individuals or firms may not be able to pledge future income, and it is plausible that banks have superior information about the value of the real estate. The model is less suited as a description of e.g. an entrepreneur (perhaps with inadequate collateral) applying for a loan to finance an investment. In that case asymmetric information about project quality is likely to be a relevant financing friction. However, the general setup can easily be altered to accommodate other frictions. A simple, but interesting model of unsecured bank lending emerges if one ignores the collateral and focus on asymmetries related to project quality, q. A sketch of such a model is given in the appendix. For example, if one considers a model where output is pledgeable and banks can learn the true project quality, one can show that three quality-regions emerge: The best projects get financing without any information being acquired, projects of intermediate quality are subject to information acquisition and are financed if good, while the worst projects do not receive financing.

Appendix

Proof of Lemma 1

A derivation of the optimal contract is given in Gorton and Ordoñez (2014). In their exposition it appears to be an unstated assumption that information acquisition, once agreed upon, is verifiable (say, because the firm can require the bank to document its findings), and I have made that assumption explicit.

This assumption could, however, be relaxed. Here I will focus on the case where $K = K^\star$ is feasible. In that case the optimal contract is $\left(R = K^\star + \frac{\gamma}{p},\ x = \frac{K^\star + \frac{\gamma}{p}}{C},\ K = K^\star\right)$. Deviating is potentially profitable because $R > K^\star$ so the bank can make profits in default states (i.e. states where the project fails). On the other hand, the collateral is on average insufficient in default states because the contract is predicated on banks actually verifying the collateral quality. The no deviation condition can be written as:

$$p[qR + (1-q)xC - K] - \gamma \geq qR + (1-q)(pxC) - K \tag{40}$$

Inserting the optimal contract and rearranging, the condition becomes:

$$\left(\frac{q}{p} + (1-q)\right)\gamma \leq (1-q)(1-p)K^\star \tag{41}$$

$K^\star$ is conceived of as being large relative to γ, and (as will be apparent from later results) information gathering only occurs for intermediate values of p. Hence, the parametric restriction is likely to satisfied as long as q is not very close to 1.

Another resolution to the incentive problem might be for the firm to always hand over the collateral at the end of the period rather than making payment out of income (when the project is successful) since that would remove any incentive to deviate. Incidentally, when information acquisition has not been agreed upon, the converse is true: it clearly is in the interest of the firms to make payments out of output whenever possible. Banks' incentive to deviate arises exactly because they have superior information about collateral value, and so firms would be worsening incentive-compatibility problems by handing over collateral. Mathematically, when firms make payments out of output, they face a constraint of the type $K \leq \frac{\gamma}{(1-p)(1-q)}$ whereas the constraint would be $K \leq \frac{\gamma}{1-p}$ if firms always handed over collateral.

Proof of Proposition 1

The firm is faced with the following maximization problem:

$$max\, \underline{p}\,[q(AK-R)-(1-q)\overline{p}xC] \tag{42}$$

or simplified slightly,

$$max\, \underline{p}qAK-pxC \tag{43}$$

Any contract must satisfy banks' participation constraint which, as shown in the main text, is given by:

$$\overline{p}xC-K\geq 0 \tag{44}$$

Using $R=\overline{p}xC$, the incentive-compatibility constraint can be written as:

$$(1-(1-\alpha)(1-q))\,\overline{p}xC-K+\frac{\gamma}{1-p}\geq 0 \tag{45}$$

The remaining constraints are:

$$1-x\geq 0 \tag{46}$$

$$K^{\star}-K\geq 0 \tag{47}$$

Observe that either the participation constraint or the incentive-compatibility constraint (or possibly both) must bind: If they did not, reducing x would always increase profits. Suppose first that the participation constraint is binding. In that case, profits are

$$\underline{p}(qA-1)K \tag{48}$$

The maximum is therefore found by choose K as large as possible subject to the other constraints. This implies that

$$K=min\{\overline{p}C,\frac{\gamma}{(1-\alpha)(1-p)(1-q)},K^{\star}\} \tag{49}$$

The first of these instances corresponds to a binding collateral constraint, the second to a binding incentive-compatibility constraint, and the third to the first-best capital allocation.

Next, suppose in contrast that the incentive-compatibility constraint is binding. In that case profits can be written as:

$$\underline{p}\left(qA - \frac{1}{1-(1-\alpha)(1-q)}\right)K + \frac{\underline{p}\gamma}{1-pq-\underline{p}(1-q)} \tag{50}$$

It follows that the optimal choice is again to choose K as large as possible, provided that $qA - \frac{1}{1-(1-\alpha)(1-q)} > 0$. If, on the other hand, $qA - \frac{1}{1-(1-\alpha)(1-q)} \leq 0$, the optimal solution must involve a binding participation constraint. Note that this parametric restriction is also consistent with both the participation and incentive-compatibility constraints binding, as in that case the optimal choice is to choose K as small as possible, corresponding to $K = \frac{\gamma}{(1-\alpha)(1-p)(1-q)}$ - see the constraint expressions immediately below.

When the incentive-compatibility constraint binds, the remaining constraints can be written as:

$$K \geq \frac{\gamma}{(1-\alpha)(1-p)(1-q)} \tag{51}$$

$$\overline{p}C\left[1-(1-\alpha)(1-q)\right] + \frac{\gamma}{1-p} \geq K \tag{52}$$

$$K^{\star} \geq K \tag{53}$$

It also follows that the participation and incentive-compatibility constraints cannot simultaneously bind when $qA - \frac{1}{1-(1-\alpha)(1-q)} > 0$ since that would involve a contradiction: We have already shown that if $qA - \frac{1}{1-(1-\alpha)(1-q)} > 0$ and the incentive-compatibility constraint binds, the choice is to choose K as large as possible, and $K = \frac{\gamma}{(1-\overline{p})(1-q)}$ is the smallest possible capital level consistent with a binding incentive-compatibility constraint.

To summarize the findings thus far, we have found that the participation constraint must bind if either $qA - \frac{1}{1-(1-\alpha)(1-q)} \leq 0$ or if $\frac{\gamma}{(1-\alpha)(1-p)(1-q)} \geq min\{\overline{p}C\left[1-(1-\alpha)(1-q)\right] + \frac{\gamma}{1-p}, K^{\star}\}$.

Conversely, a solution with a binding incentive-compatibility constraint and a non-binding participation constraint is feasible only if $qA - \frac{1}{1-(1-\alpha)(1-q)} > 0$ and:

$$min\{\overline{p}C\left[1-(1-\alpha)(1-q)\right] + \frac{\gamma}{1-p}, K^{\star}\} > \frac{\gamma}{(1-\alpha)(1-p)(1-q)} \tag{54}$$

The first of these cases corresponds to a binding collateral constraint ($x = 1$), the second to the first-best level of capital being achieved. The expression can further be simplified to read:

$$min\{\overline{p}C, K^{\star}\} > \frac{\gamma}{(1-\alpha)(1-p)(1-q)} \tag{55}$$

because:

$$\begin{aligned} \overline{p}C\left[1-(1-\alpha)(1-q)\right]+\frac{\gamma}{1-p} &> \frac{\gamma}{(1-\alpha)\,(1-p)\,(1-q)} \\ \implies \overline{p}C &> \frac{\gamma}{(1-\alpha)\,(1-p)\,(1-q)} \end{aligned} \tag{56}$$

Suppose therefore that the two conditions for a binding incentive-compatibility constraint are satisfied. Is it then the case that the incentive-compatibility constraint will, in fact, bind? In general, there are five possible cases: (1) the participation constraint and the collateral constraint bind; (2) the participation constraint and the incentive-compatibility constraint bind; (3) the participation constraint and the first-best level of capital is used; (4) the incentive-compatibility constraint and the collateral constraint bind; and (5) the incentive-compatibility constraint and the first-best level of capital is used.

I have already argued that (2) cannot be solution in this case, but can we also be sure that (1) and (3) are not solutions? Clearly, (1) and (3) also cannot be solutions as either of these cases would violate our second parametric assumption which, as shown above, could be written as:

$$min\{\overline{p}C, K^{\star}\} > \frac{\gamma}{(1-\alpha)\,(1-p)\,(1-q)} \tag{57}$$

Hence, the requirements imposed are also sufficient to guarantee a binding incentive-compatibility constraint, and (4) or (5) will be optimal depending on which is smaller of $\overline{p}C$ and $K^{\star}$.

Proof of Proposition 2

We are interested in the effects of α on $E[K]$. $E[K]$ is found by multiplying the expressions for capital from Proposition 1 by $\underline{p}$. We can summarize $E[K]$ case by case:

1. The participation and collateral constraints bind. Since $p = \underline{p}\overline{p}$: $E[K] = pC$

2. The participation and incentive-compatibility constraints bind. The use of capital can be written as $K = \frac{\gamma}{(\underline{p}-p)(1-q)}$, and via a few manipulations: $E[K] = \frac{\gamma}{(1-\overline{p})(1-q)}$

3. The participation constraint binds, and $K = K^{\star}$: $E[K] = \underline{p}K^{\star}$

4. The incentive-comp. and collateral constraints bind: $pC\left[1-(1-\alpha)(1-q)\right]+\frac{p\gamma}{1-p}$

5. The incentive-compatibility constraint binds, and $K = K^{\star}$: $E[K] = \underline{p}K^{\star}$

It is evident that α has no influence on capital use in case 1. In cases 3 and 5, more ignorance (higher α) is detrimental to welfare as $\underline{p} = p + (1-\alpha)(1-p)$. In case 2, more ignorance is always beneficial as a higher α leads to an increase in $\overline{p}$ and therefore also to an increase in the expression as a whole. In case 4, the partial derivate w.r.t. α equals $p(1-p)C - \gamma$, and the effect is unclear.

Generally, though, we think of C as being large relative γ, in which case the effect is positive.

Proof of Lemma 2

See the main text.

Proof of Proposition 3

See the main text.

Proof of Proposition 4

See the main text.

Proof of Proposition 5

As noted in the main text, the threshold value of α below which information acquisition is optimal is implicitly defined by the following equation:

$$p(qA-1)K^{\star}-\gamma=(qA-1)\frac{\gamma}{(1-\overline{p})(1-q)} \tag{58}$$

where $\frac{1}{1-\overline{p}}$ is an increasing function of α. It is then straightforward to find the claimed effects by implicit differentiation. Here I show the case of project quality (A) - the effects relating to the other parameters can be derived similarly.

Implicit differentiation of the above equation w.r.t. A gives:

$$pqK^{\star}=q\frac{\gamma}{(1-\overline{p})(1-q)}+(qA-1)\frac{\gamma}{1-q}\frac{d}{d\alpha}\left(\frac{1}{1-\overline{p}}\right)\frac{dA}{d\alpha} \tag{59}$$

Rearranging,

$$q\left(pK^{\star}-\frac{\underline{p}\gamma}{(1-\overline{p})(1-q)}\right)=(qA-1)\frac{\gamma}{1-q}\frac{d}{d\alpha}\left(\frac{\underline{p}}{1-\overline{p}}\right)\frac{d\alpha}{dA} \tag{60}$$

From the equation defining the threshold value, it follows that:

$$pK^{\star}-\frac{\gamma}{(1-\overline{p})(1-q)}=\frac{\gamma}{qA-1}>0 \tag{61}$$

Hence, the left-hand side of (60) is positive, and it therefore must be the case that $\frac{d\alpha}{dA}>0$.

Proof of Proposition 6

The assumption is that either all agents have full information in advance or will gather it as a consequence of the imminent crisis, which takes place at the beginning of the period. The hypothetical we consider is then: Would agents have been better off if agents had been gathered prior to the shock? Here the signal and information cost can be ignored as the same amount of information acquisition takes place whether information is acquired early or upon the occurrence of the shock. (Note: The information cost could be higher with early information acquisition if the shock were large enough for $p = \eta$ to be in the information-acquisition region.)

If agents had full information in advance of the shock, the initial distribution of beliefs would be $f(0) = 1 - p$ and $f(1) = p$. Upon the occurrence of the shock, a fraction $1 - \eta$ of collateral turns bad, but agents do not know which is bad. The ex post distribution is therefore $f(0) = 1 - p$ and $f(\eta) = p$. Welfare is proportional to capital usage, which is $pK(\eta)$.

This must be compared to the case where information is gathered by uninformed agents, of which there is fraction α, once the shock occurs. In that case the initial distribution is $f(0) = (1 - \alpha)(1 - p)$, $f(p) = \alpha$, and $f(1) = (1 - \alpha)p$. Upon the occurrence the shock, the distribution becomes: $f(0) = (1 - \alpha)(1 - p) + \alpha(1 - \eta p)$, $f(\eta) = (1 - \alpha)p$, and $f(1) = \alpha\eta p$. The associated capital usage (which, again, is proportional to welfare) is: $(1 - \alpha)pK(\eta) + \alpha\eta pK^\star$.

The difference between waiting for the shock and having information in advance is therefore:

$$\alpha p \left(\eta K^\star - K(\eta)\right) \tag{62}$$

For any moderately-sized shock this quantity is negative. Clearly, the expression is negative whenever η is such that $K(\eta) = K^\star$ and also for many values of η when $K(\eta) = \frac{\gamma}{(1-\eta)(1-q)}$. Also, if the shock is very large, it may cause those agents who are informed in advance to have to reacquire information. There is, however, one case where waiting for the shock is optimal. If the shock is very large, but not quite large enough to induce information acquisition, waiting is optimal. This is the case when:

$$\frac{\gamma}{qA - 1} \geq \eta K^\star - \frac{\gamma}{(1 - \eta)(1 - q)} \geq 0 \tag{63}$$

Proof of Proposition 7

Suppose the economy starts from a state of full information at time 0, i.e. $\alpha(0) = 0$, after which information gradually decays until some stopping time $\bar{t}$ at which point all uninformed agents are forced to reacquire information by central bank collateral policy. At that point $\alpha(\bar{t}) = 0$ again, and so the whole process repeats itself in cycles. We can then formulate the problem is one of finding the highest level of welfare per cycle, scaled by the length of the cycle, i.e. $\frac{1}{\bar{t}}$ multiplied by the profits attained during the cycle.

It is easier to do the calculations in continuous rather than discrete time since an optimal stopping time is likely to be placed somewhere between two discrete time values. (And the qualitative features of the solutions, which are the ones we are interested in, are the same.) The continuous-time equivalent of the discrete-time formulation is that information decays at a rate $d\alpha = \lambda(1-\alpha)dt$ with $\alpha(0) = 0$, hence $\alpha(t) = 1 - e^{-\lambda t}$. Also, to simplify the resulting expressions I ignore discounting by setting $\beta = 1$ and consider the case of $K(p, \alpha) = K^\star$ since it is in that region that information acquisition becomes relevant. In that case we are looking to find the stopping time $\bar{t}$ which results in the highest average level of welfare, i.e.:

$$\frac{1}{\bar{t}}\left[\int_0^{\bar{t}} e^{-\lambda t} p(qA-1)K^\star dt + \int_0^{\bar{t}} \left(1-e^{-\lambda t}\right)\left(p + e^{-\lambda t}(1-p)\right)(qA-1)K^\star dt - \left(1-e^{-\lambda \bar{t}}\right)\gamma\right] \tag{64}$$

The first integral expresses is the welfare of informed agents, the second the welfare of uninformed agents, and finally there is the information cost to be paid, which is proportional to the fraction of uninformed agents at time $\bar{t}$. Solving for he first-order condition w.r.t. $\bar{t}$ and simplifying produces:

$$\frac{(1-p)(qA-1)K^\star}{\lambda\gamma} = \frac{1-e^{-\lambda\bar{t}} - \lambda\bar{t}e^{-\lambda\bar{t}}}{(1-e^{-\lambda\bar{t}} - \lambda\bar{t}e^{-\lambda\bar{t}}) - \frac{1}{2}\left(1-e^{-2\lambda\bar{t}} - 2\lambda\bar{t}e^{-2\lambda\bar{t}}\right)} \tag{65}$$

Now, the expression on the right-hand side is a decreasing function of $\bar{t}$ when $\bar{t} > 0$. It therefore follows by implicit differentiation that:

$$\frac{d\bar{t}}{d\gamma} > 0 \tag{66}$$

$$\frac{d\bar{t}}{d\lambda} > 0 \tag{67}$$

$$\frac{d\bar{t}}{dp} > 0 \tag{68}$$

$$\frac{d\bar{t}}{d((qA-1)K^\star)} < 0 \tag{69}$$

Proof of Proposition 8

Proposition 5 in Gorton and Ordoñez (2014) shows that the recovery from a crisis is faster if information is generated after the shock when $\eta p < \frac{1}{2} + \sqrt{\frac{1}{4} - \frac{\gamma}{K^\star(1-q}}$. We take p to be such that $K(p) = K^\star$. This is therefore a requirement that the shock be adequately large.

It follows - see Corollary 2 of the same paper - that there exists a range of aggregate shocks η such that $\eta p \in \left[p_h, \frac{1}{2} + \sqrt{\frac{1}{4} - \frac{\gamma}{K^\star(1-q}}\right]$, in which agents do not gather information, but the recovery would be faster if they did. Here p_h is defined as the collateral quality at which agents are indifferent between gathering and not gathering information (parametrically, the larger of the two solutions to the quadratic equation defined by: $p(qA-1)K^\star - \gamma = \frac{\gamma}{(1-p)(1-q)}$.

Finally, note that this region overlaps with the region in which the central bank optimally applies a strict collateral policy: see the discussion in the main text.

Sketching a model of unsecured bank lending

I the conclusion I alluded to the fact that the setup in Gorton and Ordoñez (2014) can easily be adapted to serve as a simple model of e.g. unsecured lending, which might be interesting in own right. At least it reproduces certain features of real-life bank lending. For example, it explains the observation that banks typically accept loan applications immediately if borrowers are perceived to be of high quality, subject loans to further review if they are of intermediate quality, and reject them immediately if they are of low quality, see e.g. Berg (2015).

To see this, consider a firm with the same technology as in the main text, i.e. a project which pays AK with probability q and nothing with probability $1-q$, but now assume that this income is pledgeable. Consider first the case where the firm applies for a loan of fixed size, K, promising to repay a bank an amount, R.

Assume now that the bank can verify the true project quality at cost γ prior to lending at cost γ. If banks are competitive, their participation constraint binds, informed lending must entail:

$$q(R-K)-\gamma=0 \tag{70}$$

Hence,

$$R=K+\frac{\gamma}{q} \tag{71}$$

Profits for firms under informed lending are then $q(AK-R)=(qA-1)K-\gamma$.

For uninformed lending to take place, it must satisfy both a participation and an incentive-compatibility constraint. These are:

$$qR\geq K \tag{72}$$

$$qR-K\geq q(R-K)-\gamma\Rightarrow\frac{\gamma}{1-q}\geq K \tag{73}$$

Clearly, the participation constraint will always bind, so firm profits are $(qA-1)K$. Hence, uninformed lending dominates informed lending whenever it is feasible, which is when $q\geq 1-\frac{\gamma}{K}$. For lower q, informed lending takes place as long as it is profitable for firms, which is when $q\geq\frac{1+\frac{\gamma}{K}}{A}$. Hence, the model produces three q-regions: 1) a region with uninformed lending $\left[1,\,1-\frac{\gamma}{K}\right]$, a 2) region with informed lending $\left[1-\frac{\gamma}{K},\,\frac{1+\frac{\gamma}{K}}{A}\right]$ (which exists whenever profitability is adequately high relative to information costs, specifically when $\frac{A-1}{A+1}\geq\frac{\gamma}{K}$), and 3) a region in which no lending takes place $\left[\frac{1+\frac{\gamma}{K}}{A},\,0\right]$.

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