

Efficiency and Bargaining Power in the Interbank Loan Market*

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Abstract

Using detailed transactions-level data on interbank loans, we examine the efficiency of an overnight interbank lending market, and the bargaining power of its participants. Our analysis relies on the equilibrium concept of the *core*, which imposes a set of no-arbitrage conditions on trades in the market. For Canada's *Large-Value Transfer System*, we show that while the market is fairly efficient, systemic inefficiency persists throughout our sample. The level of inefficiency matches distinct phases of both the Bank of Canada's operations as well as phases of the 2007-2008 financial crisis. We find that bargaining power tilted sharply towards borrowers as the financial crisis progressed, and (surprisingly) towards riskier borrowers.

Keywords: interbank markets, cooperative bargaining, financial institutions

JEL classifications: C71, G21, G28, E58

Running head: Efficiency in Interbank Lending

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1 Introduction

Multilateral trading markets are endemic in modern economies with well-known examples such as the bargaining over tariffs and similar trade barriers among WTO countries, monetary and fiscal policy-making among European Union countries, co-payment rate determination among hospital and insurance company networks, and even trades of players among professional sports teams. Our paper presents a novel approach to empirically assess the *efficiency* of these markets, and the *bargaining power* of the different agents in the market. We study the Canadian interbank market for overnight loans.

A serious impediment to the analysis of efficiency and bargaining power in real-world trading environments is the complexity of the markets themselves. The players are engaged in a complicated game of imperfect competition, in which some of their actions are restricted by trading conventions, but where the players may communicate and send signals in arbitrary ways. Even if we could write down a formal model that would capture the interactions among players, it would be difficult to characterize the equilibrium of such a game—a prerequisite to any analysis of bargaining and efficiency. Moreover, the outcome of such a game greatly depends on the assumed extensive-form. For example, outcomes can vary according to the sequencing of offers (who is allowed to make an offer to whom and when), as well as the nature of information asymmetries among the players. For these reasons, a complete “structural” analysis of such imperfectly competitive bargaining environments seems out of the question.

In this paper we take a different approach. Instead of modeling the explicit multilateral trading game amongst market participants, we impose an equilibrium assumption on the final outcome of the market. Our approach is methodologically closer to general equilibrium theory than to game theory: We use the classical equilibrium concept of the *core*. The core simply imposes a type of *ex-post no-arbitrage condition* on observed outcomes; it requires that the outcome be immune to defection by any subset of the participating players. Many alternative equilibrium concepts would imply outcomes in the core, but the advantage for our purposes is that the core is “model free,” in the sense that it does not require any assumptions on the extensive-form of the game being played. As we shall see, the relatively weak restrictions of the core concept nevertheless allow us to draw

some sharp conclusions about how efficiently the Canadian interbank market functioned, in the years preceding, and during, the most recent economic crisis.

Subsequently, for outcomes which are in the core, we define a simple measure of how much the observed outcomes favor particular market participants: specifically, borrowing versus lending banks in the interbank market. We use this measure as an indicator of bargaining power, and analyze its relationship to characteristics of the market and its participants. Thus, in our paper *efficiency* means the degree to which the absence of arbitrage conditions imposed by the core are satisfied, and *bargaining power* results from the position of the outcomes in the core. If the outcome is relatively more favorable to some agents, we shall say that these agents have enjoyed greater bargaining power.

We study the Large Value Transfer System (LVTS) in Canada, which is the system the Bank of Canada uses to implement monetary policy. Throughout the day, LVTS participants send each other payments and at the end of the day have the incentive to settle their positions to zero. If there are any remaining short or long positions after interbank negotiations these must be settled with the central bank at unfavorable rates. Participants are therefore encouraged to trade with each other in the overnight loan market. This market is ideal for study for various reasons: first, the market operates on a daily basis among seasoned players, so that inexperience or naïvete of the players should not lead to any inefficiencies. Second, there is a large amount of detailed data available on the amount and prices of transactions in this market. Finally, the LVTS is a “corridor” system, meaning that interest rates in the market are bounded above and below, respectively, by the current rates for borrowing from and depositing at the central bank. This makes it easy to specify the outside options for each market participant, which is a crucial component in defining the core of the game; at the same time, the corridor leads to a simple and intuitive measure of bargaining power between the borrowers and lenders in the market.¹

Several researchers have explicitly modeled the decision of market participants in environments

¹Since Canada operates a corridor system, outside options are symmetric around the central bank’s target rate and changes to the target do not arbitrarily favor one side or another of the market. In contrast, in overnight markets without such an explicit corridor, both the outside options and bargaining power are not as convenient to define. Many central banks use a corridor system – e.g. the ECB. The Federal Reserve and Bank of Japan, however, use reserve regimes. Corridor systems rely on standing liquidity facilities whereas reserve regimes rely on period-average reserve requirements. See Whitsell (2006) for a discussion.

similar to LVTS. For example, Ho and Saunders (1985), Afonso and Lagos (2011), Duffie and Gârleanu (2005), Duffie, Gârleanu, and Pedersen (2007), and Atkeson, Eisfeldt, and Weill (2013) examine the efficiency of the allocation of funds in the Federal funds market or over-the-counter markets, more generally.² The systems, markets and agents under study in this paper have previously been examined in Chapman, McAdams, and Paarsch (2007), Hendry and Kamhi (2009), Bech, Chapman, and Garratt (2010), and Allen, Hortaçsu, and Kastl (2011).

Moreover, as previously mentioned, the core imposes, essentially, no-arbitrage conditions on the trades in the interbank market, so that inefficient outcomes – those which violate the core conditions – are also those in which arbitrage opportunities were not exhausted for some coalition of the participating banks. Thus, our analysis of the interbank market through the lens of the the core complements a recent strand in the theoretical finance literature exploring reasons for the existence and persistence of “limited arbitrage” in financial markets (see Gromb and Vayanos 2010 for a survey of the literature).

A market outcome is the result of overnight lending between financial institutions at the end of the day: the outcome consists of the payoffs to the different banks. We (1) check if each outcome is in the core (this can be done by simply checking a system of inequalities), and (2) measure the degree to which outcomes are aligned with the interests of net borrowers or lenders in the system: our measure of bargaining power. We proceed to outline our results.

In the “normal” pre-crisis period, 2004-2006, the system largely complies with the core: it is efficient and there are few deviations from the absence of arbitrage. The bargaining power measure generally hovers around 0.5, meaning that borrowers and lenders are equally favored (this would be consistent with recent search models of the OTC markets which assume a bargaining weight of 0.5). During periods when the risk prospects of borrowing banks rise above average, our bargaining power favors the lender, meaning that a lender can command higher interest rates if it lends to banks in riskier circumstances.

With the onset of the crisis in 2007, however, interesting changes happen. There is generally an increase in the number of violations of the core, so that the market becomes less efficient (in absolute terms, though, the inefficiencies are never very large). During the financial crisis the Bank

²An interested reader can find a book length treatment of the economics of OTC markets in Duffie (2012).

of Canada increased its injections of cash to the LVTS as part of a global initiative to provide banks with liquidity. We find, however, that these injections are positively correlated with violations of the core both in the crisis period and pre-crisis. The additional cash tends to lead to situations where arbitrage opportunities are left unexploited.

Also, the financial crisis brought about a shift in bargaining power to favor borrowers; indeed, increased levels of risk are associated with changes in bargaining power *to favor borrowers*. That is, during the crisis period, when a borrowing bank (on the short side in the interbank market) becomes riskier according to standard measures of counterparty risk (including Merton's 1974 "distance to default" measure and credit default swap (CDS) prices), it receives better terms (or at least no worse) in the interbank loans market. These results contrast with our findings for the "normal" non-crisis period where risk and prices are positively correlated.

The needs for funds during the crisis should, as one might expect, have favored lenders. Instead, we see borrowers obtaining better terms, and (surprisingly) a positive correlation between borrowers' bargaining power and measures suggesting increasing default risk in the market. In turn, we find that more core violations are associated with higher bargaining power for the borrowers.

Our findings are consistent with lenders being more lenient with borrowers, and in particular with the borrowers who were subject to higher levels of risk (be it at the level of the individual bank, or the system) during the financial crisis. One possibility for the additional core violations during the crisis reflects banks being less concerned with exploiting arbitrage opportunities in periods of stress.

Overall, these findings suggest that banks within the Canadian overnight market continued to lend to risky counterparties despite the increasing risk in the market. However, such actions were not directly supported or guaranteed by regulators; indeed, unlike in the U.S., no bail-outs or other forms of support were ever mentioned or undertaken in the Canadian financial sector. Rather, the observed effects appear to be a spontaneous reaction among the players in the market, and support the sentiment of then-Governor of the Bank of Canada David Dodge, who stated that "we have a collective interest in the whole thing (*sic* [the Canadian financial system]) not going into a shambles." While this is consistent with a "weak" version of a too-big-to-fail hypothesis, it may also reflect heterogeneity in (il)liquidity across banks, which are captured in the bank-level default

variables used in our analysis.³

We explore in detail one potential explanation for this result. For our sample, we show that banks bounce back and forth frequently between lending and borrowing in the interbank market. This fact, coupled with the repeated interaction which characterize the Canadian interbank market, may have led to an outcome whereby lending banks refrain from exploiting borrowers during difficult times, instead lending to them at favorable rates under the consideration that such benevolent behavior may be reciprocated in the future when the banks find themselves on opposite sides of the market.⁴ This interpretation of our results is consistent with Carlin, Lobo, and Viswanathan’s (2007) model of “apparent liquidity” in oligopolistic lending markets. Acharya, Gromb, and Yorulmazer (2012) construct a model in which “strong” banks exercise market power over “weak” banks which do not have other non-central bank outside options. Our findings suggest, to the contrary, that stronger lending banks appear to refrain from exercising market power over weaker borrowers.

The remainder of the article is organized as follows. Section 2 presents the data. Section 3 discusses the methodology, both conceptually and how we implement it using the Canadian overnight interbank lending market. Section 4.3 presents the results while section 5 discusses their economic significance. Section 6 concludes.

2 The Canadian Large Value Transfer System (LVTS)

The primary data for our analysis comes from daily bank transactions observed in Canada’s Large Value Transfer System (LVTS). LVTS is Canada’s payment and settlement system and it is operated by the Canadian Payment Association. LVTS is a tiered system, similar to CHAPS in the United Kingdom, but unlike Fedwire in the United States. That is, there are a small number of direct

³The TBTF hypothesis has been widely discussed and circulated in both the academic (O’Hara and Shaw (1990), Rochet and Tirole (1996), Flannery (2010)) and nonacademic financial press (Sorkin (2009), Krugman (2010)).

⁴It might also be the case that providing favorable trades in the overnight interbank market is done in exchange for favorable trades the other way in the overnight repo market. We do not have data on repo transactions other than CORRA which is the average rate and which did not deviate from target as much as the interbank rate. However, given that the repo market is dominated by securities firms and the interbank market is managed by cash managers at banks suggests that there is not much room for this type of multi-firm-multi-desk/subsidiary bargaining.

participants (15) and a larger number of indirect participants.⁵ The direct participants in LVTS are the Big 6 Canadian banks (Banque Nationale, Bank of Montreal, Bank of Nova Scotia, Canadian Imperial Bank of Commerce, Royal Bank of Canada, Toronto-Dominion Bank), HSBC, ING Canada, Laurentian Bank, State Street Bank, Bank of America, BNP Paribas, Alberta Treasury Branches, Caisse Desjardins, and a credit union consortium (Central 1 Credit Union). State Street joined LVTS in October 2004 and ING joined in October 2010.

Throughout the day payments are sent back-and-forth between direct participants. Like real-time gross settlement systems (RTGS), finality of payment sent through LVTS is in real-time; however, settlement in LVTS occurs at the end of the day. Relative to a RTGS system, the LVTS system has higher cost for survivors given default, but also substantial cost savings since banks do not need to post as much collateral. This is because most transactions in Canada are sent via a *survivors pay*, or partially collateralized, tranche. The cost of a partially collateralized system is an increase in counterparty risk. Participants manage counterparty risk by setting bilateral credit limits at the beginning of each day and also manage these limits throughout the day.⁶ Allen, Hortaçsu, and Kastl (2011) find, however, that even during the financial crisis direct participants did not lower their credit limits. They take this as evidence that there was no meaningful increase in counterparty risk in the payments system during the crisis.

2.1 Data Description

We are interested in studying the price and quantity of interbank overnight loans. Our period of analysis is April 1, 2004 to April 17, 2009. As flows in LVTS are not classified explicitly as either a payment or a loan, we follow the existing literature (eg. Acharya and Merrouche 2013, Afonso,

⁵Indirect participants are outside LVTS and are the clients of the direct participants. LVTS is smaller than most payment platforms in that there are few participants, although similar to CHAPS. CHAPS, for example, has 16 participants. The Statistics on Clearing and Settlement Systems in the CPSS Countries volume 1 and 2, November 2011, 2012 list the following number of participants for the following countries: Australia (70), Brazil (137), India (118), Korea (128), Mexico (77), Singapore (62), Sweden (21), Switzerland (376), Turkey (47). Fedwire in the U.S. has about 8,300, although Afonso, Kovner, and Schoar (2011) find that about 60% of a banks loans in a month typically come from the same lender.

⁶There are additional limits on counterparty risk imposed in the system. For more details on LVTS see Arjani and McVanel (2010).

Kovner, and Schoar 2011) and use the Furfine (1999) algorithm to extract transactions which are most likely to be overnight loans, among the thousands of daily transactions between the banks in the LVTS. The Furfine algorithm picks out overnight loans by focusing on transactions sent, for example, from bank A to B towards the end of the day (for robustness we study two different windows: 4-6:30pm, and 5-6:30pm; but we only report results for the latter) and returned from B to A the following day before noon for the same amount plus a mark-up equal to a rate near the Bank of Canada’s target rate. We are relatively loose with the definition of ‘near’, allowing financial institutions to charge rates plus or minus 50 basis points from target (financial institutions that are short can borrow from the central bank at plus 25 basis points and those that are long can lend to the central bank at minus 25 basis points). This approach allows us to identify both the quantity borrowed/lent and at what price.

Armantier and Copeland (2012) have examined the ability of the Furfine algorithm to correctly identify interbank transactions. They find that the Type 1 error of the algorithm (i.e. misidentify payments as loans) is problematic in Fedfunds data matched to actual interbank transactions. This is particularly true for transactions early in the day as well as small transactions.⁷

We are confident that this problem is not present in our dataset for multiple reasons. First, the Canadian interbank market is a much simpler market than the US market; for example, there are no Euro-dollar transactions or tri-party repo legs that are found to be the primary culprits for the Armantier and Copeland (2012) study. Second, we focus our sample to only large end-of-day payments when the LVTS is setup only to accept bank-to-bank loan transactions. Third, Rempel (2014) conducts a careful study of the application of Furfine algorithm to LVTS data and finds a relatively low Type 1 error rate of between 5% and 12%. As discussed below we take this Type 1 error into account when estimating bargaining power.

Figure 1 plots both the total loan amounts and average loan size for transactions in LVTS

⁷Kover and Skeie (2013) also assess the quality of Fedwire payments data and conclude that the data is a good representation of overnight interbank activity, if not the stricter set of Fed Funds activity. The success of the Furfine algorithm at identifying interbank lending has been studied for a number of markets, including the Bank of England’s CHAPS Sterling settlement system (c.f. Wetherilt, Zimmerman, and Soramäki (2009) and Acharya and Merrouche (2013)), Switzerland (Guggenheim and S. Kraenzlin (2010)), and the Eurosystem real-time gross settlement system, TARGET2 (Arciero et al. (2013)).

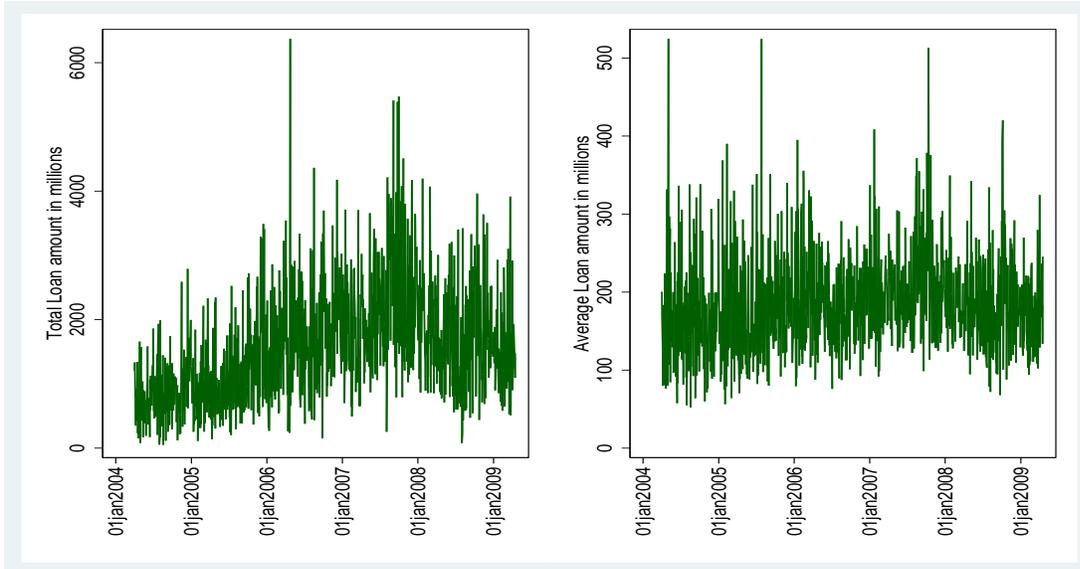


Figure 1: Loan Quantities in LVTS

after 5pm between April 2004 and April 2009. All transactions are in Canadian dollars. On the average day approximately 1.55 billion is transacted, about 186 million per financial institution. By construction the smallest loan is 50 million; the largest loan is 1.7 billion. Aside from the large spike in transactions in January 2007, the key noticeable pattern is the increase in loan amounts in the summer and fall of 2007. The sum of daily transactions in this period were consistently above \$3 billion. This coincides with the Asset-Backed Commercial Paper (ABCP) crisis in Canada.⁸ At the time the market for non-bank issued ABCP froze and banks had to take back bank-issued ABCP on their balance sheet. By July 2007, the ABCP market was one-third of the total money market and when maturities came due and were not renewed this created substantial stress on other sources of liquidity demand. Irrespective of the freezing of the ABCP market, however, direct participants in LVTS continued lending to each other. But at what price did this lending occur?

Figure 2 plots the average spread to the target rate and its standard deviation for transactions

⁸ABCP is a package of debt obligations typically enhanced with a liquidity provision from a bank. In Canada the bank providing the liquidity only has to pay out under catastrophic circumstances and was not even triggered during the financial crisis. In addition, the regulator did not require banks to hold capital against the provision. Under these rules the market approximately doubled between 2000 and 2007 to \$120 billion.

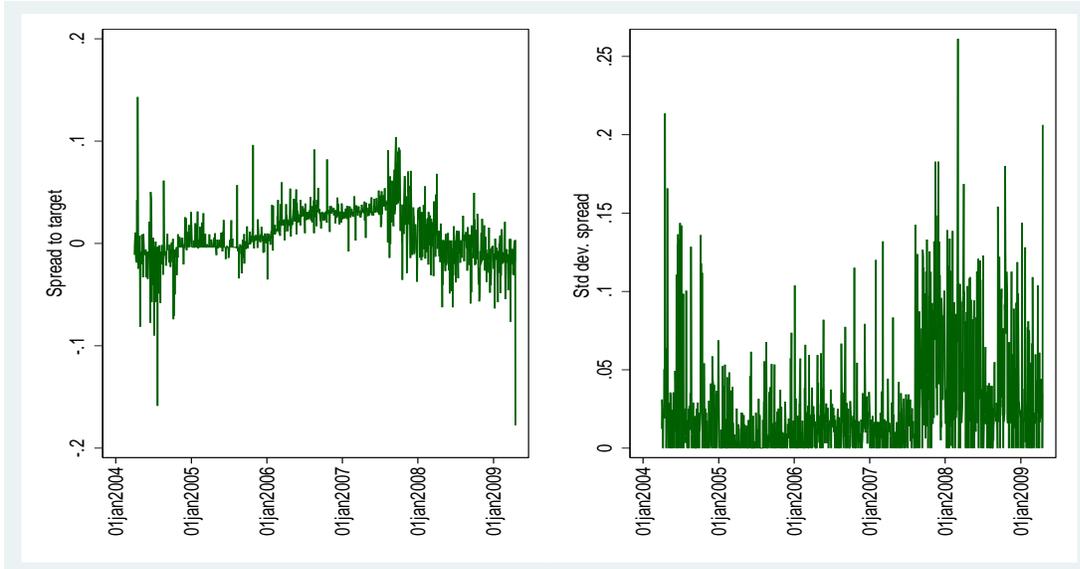


Figure 2: Loan Prices in LVTS

sent after 5pm between April 2004 and April 21, 2009. Prior to the summer of 2007, i.e. normal times, the average spread to target is close to zero. Throughout 2007, however, financial institutions did increase the price of an overnight uncollateralized loan. Between August 9th, 2007 and October 11th, 2007 the average spread to target was about 4.8 basis points.⁹ Somewhat surprisingly the spread to target post-October 2007 is 0, and -0.7 basis points in the six weeks following the collapse of Lehman Brothers. Allen, Hortaçsu, and Kastl (2011) find that LVTS participants demand for term liquidity was substantial only in this period.

2.2 Monetary policy and Liquidity policy

Monetary policy has been implemented in Canada since 1999 through LVTS (Reid 2007). At the end of the day any short or long positions in LVTS must be settled, either through interbank trades or with the central bank at a penalty rate.¹⁰ The interest rate corridor (the difference between the

⁹The start of the ABCP crisis is recognized to be August 9th (Acharya and Merrouche (2013)). The Bank of Canada held its first liquidity auction on October 12th, 2007 although by February 15, 2007 the Bank of Canada had already abandoned its zero balance target in the overnight market.

¹⁰All LVTS participants (foreign and domestic) have access to borrowing and lending facilities.

rate on overnight deposits and overnight loans) is set so that banks have the right incentives to find counterparties among themselves to settle their positions. The midpoint of the corridor is the interest rate that the central bank targets in its execution of monetary policy.

The symmetry of the interest rate corridor is meant to encourage trading at the target rate. Within a corridor system a central bank can increase the supply of liquidity without excessively lowering the target rate since it is bounded below by the deposit rate. Therefore a central bank operating a corridor can provide liquidity to LVTS participants (liquidity policy) without lowering nominal rates “too much” (monetary policy).

Unlike in the U.S., (e.g. Armentier et al. 2011) there is also no documented stigma for participants depositing funds or borrowing from the central bank using the standing liquidity facility, which is the facility modeled in this paper. There might be stigma, however, for participants considering using emergency liquidity assistance (ELA). ELA is only extended on exceptional bases to institutions that are considered solvent and able to post collateral but have severe liquidity issues. Given that ELA invites greater scrutiny from the central bank there might be stigma. The standing lending facility loans that are available to banks analyzed in this paper are not at a penalty and accessed frequently by all borrowers, approximately 10% of transactions a month, and therefore different from ELA or discount window loans in the U.S.

When the Bank of Canada first implemented LVTS, it required participants to close out their long and short positions completely and leave cash settlement balances at zero to avoid penalty rates – that is, the central bank targeted “zero excess liquidity” during this initial period.

Upon implementation of LVTS, however, there was substantial volatility in the overnight (lending) rate; moreover, this overnight rate tended to be above the target monetary policy rate. Therefore, in 1999, the Bank started allowing positive “settlement balances”; what this meant was that at the end of the trading day, market participants would, in aggregate, be allowed to have long positions in LVTS settlement funds. This served to reduce the overnight rate toward the target rate at the middle of the corridor.

Effectively, then, controlling the amount of cash settlement balances was a means for the Bank of Canada to inject liquidity into this market as needed. Liquidity and cash settlement balances are therefore used interchangeably throughout the text. In November 1999, this limit was around \$200

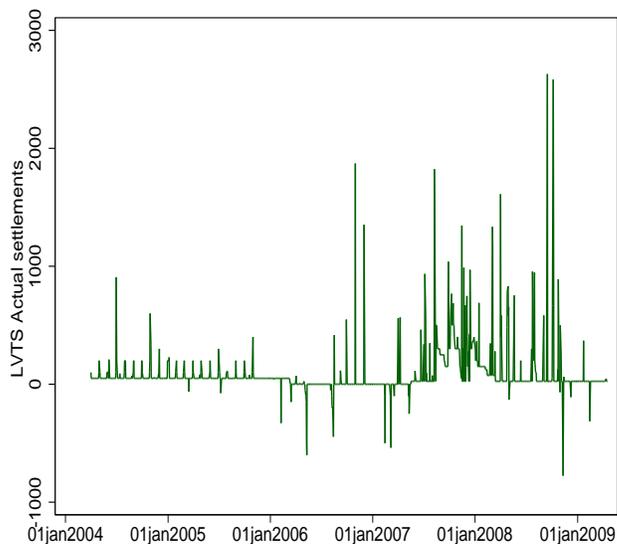


Figure 3: Actual Cash Settlement Balances in LVTS (central bank liquidity)

million, which was distributed among the 15 LVTS participants at that time via a series of auctions that were also used for investing the Government of Canada’s cash holdings. In 2001 the Bank of Canada lowered the amount of liquidity to \$50 million, and the system remained stable until the end of 2005. Starting in March 2006, faced with strong downward pressure on the overnight rate, the Bank of Canada implemented a low liquidity policy by reducing the required balance back to zero, thereby not allowing participants to an aggregate long position at the end of the day. This regime continued until mid-February 2007 when, on the eve of the financial crisis, the Bank of Canada joined other central banks in injecting liquidity into the banking system. Cash settlement balances were increased to \$500 million. Figure 3 presents the cash settlement balances in LVTS at the end of each day between April 2004 and April 2009.

Since we expect these shifts in liquidity policy would naturally affect efficiency in the LVTS, our subsequent empirical analysis focuses on how efficiency and bargaining power changed across the three periods just discussed: First, April 1, 2004 to February 28, 2006, a period of stability in the Canadian interbank market. Second, March 1, 2006 to February 14, 2007, a period of no regular liquidity injections by the central bank. Third, the financial crisis: February 15, 2007 to April 20,

3 Methodology

We present a cooperative bargaining model of the market for overnight loans, and use it to study efficiency and bargaining power. We prefer this cooperative approach to a noncooperative (game-theoretic) model of bargaining which is, as is well-known, sensitive to the specific assumed extensive-form: it depends on the order in which offers are made, on the assumptions of player communication, and the information that they possess. Given that we study the volatile period surrounding the financial crisis of 2008, the assumption that a stable extensive form bargaining model is valid throughout this period would be quite strained. The crisis period is very unlikely to fit any version of known extensive-form bargaining models.

Instead of a game-theoretic model of bargaining, we apply the concept of the *core* to an interbank loan market. Essentially, the core is a basic “no-arbitrage” requirement; we show that it can be used to investigate the bargaining power of the financial institutions in the system. We can estimate a simple measure of bargaining power of the institutions who had a need for funds, versus those that held a positive position in the market for interbank loans.

The cooperative approach assumes that agents can make binding commitments. In contrast, a non-cooperative model would need to construct explicit commitments through repeated-game effects. Repeated games are empirically complicated because they tend to predict too little. Our approach gives a set-valued prediction (the core of the market), so we shall not predict a unique allocation of trades; but, as we shall see, the prediction is still quite sharp and useful. At the same time, for allocations which are within the core, we can naturally construct a measure of bargaining power, by looking at whether the observed allocation favors lenders or borrowers in the market more.

We should note that the necessary conditions we derive below do not assume homogeneity of banks in the market. At the same time they are not incorporating any sort of bank-level heterogeneity

¹¹We are being conservative in starting the financial crisis in February 2007 rather than August 2007 as is typically assumed. Excluding the period February 2007 to July 2007 does not affect the conclusions. The reason is that throughout the spring and summer of 2007 there were already concerns about liquidity in the overnight market with the Bank of Canada abandoning its zero target; see Reid (2007).

either. Instead they are purely implications of the payoffs in LVTS and whether those payoffs are dominated by another set of trades between the same group of banks. The crucial assumption, therefore is that borrowers are not treated as different risks by different lenders.

The market has n agents, each with a net position (at the end of the day) of $\omega_i \in \mathbf{R}$. The central bank sets a *target rate* r . It offers each bank (collateralized) credit at the *bank rate* $b = r + 25$, and pays the *deposit rate* $d = r - 25 > 0$ on positive balances. These rates are fixed “take it or leave it” offers, and hence we use these as the benchmark from which to calculate bargaining power. In a sense, the central bank has the maximum bargaining power in this market, and we use its rates to calibrate the bargaining power of other agents.

We assume that $\sum_i \omega_i = 0$, so that positive and negative balances in the aggregate cancel out.¹² In this setup, agents have incentives to trade with each other at rates somewhere in the band.

Define a characteristic function game by setting the stand alone value for a coalition $S \subseteq N = \{1, \dots, n\}$ as:

$$(1) \quad \nu(S) = \begin{cases} b \sum_{i \in S} \omega_i & \text{if } \sum_{i \in S} \omega_i \leq 0 \\ d \sum_{i \in S} \omega_i & \text{if } \sum_{i \in S} \omega_i > 0 \end{cases} .$$

These inequalities present the idea that the best a coalition S can do is to use multilateral negotiations to pool their net positions, and then deposit (borrow) the pooled sum $\sum_{i \in S} \omega_i$ at the Bank at the rate d (b). Implicit is the assumption that a coalition can achieve individual payoffs that add up to $\sum_{i \in S} \omega_i$; this would not be true if the agents were risk averse, or if banks could be forced to trade at fixed rates. Note that banks may be fully heterogeneous, as long as the heterogeneity does not constraint the rates at which specific subsets of banks can make transfers.

The payoff to a bank is simply a number, x_i , which is the net position of that bank, ω_i , multiplied by the bank’s negotiated rates (y_i). The *core* of ν is the set of rates (y_1, \dots, y_n) such that: (i) $\sum_{i \in N} y_i \omega_i = 0$ (this is just an accounting identity that among all the banks net payments and outlays must cancel out); and, (ii) for all coalitions S , $\sum_{i \in S} y_i \omega_i \geq \nu(S)$. That is, any coalition must obtain a payoff exceeding its stand-alone value.

¹²It is easy to accommodate $\sum_i \omega_i$ of any magnitude in the analysis below, but since we calculate balances from transactions data, $\sum_i \omega_i = 0$ is always satisfied automatically in our data.

Intuitively, the core of this game is the set of rates which are “immune” to multilateral negotiations on the part of any coalition S (which would result in the coalition payoff $\nu(S)$ defined in equation 1). A simpler approach is to calculate bilateral interest rates on specific loans between banks, and see how often they lie within the band (d, b) . We focus on the core instead because we want to look at the bank’s daily operation, not at specific loans, and (more importantly) because we want to account for deals that may involve more than one bank and the central bank.

3.1 The Core of the Interbank Market

We first derive some simple necessary conditions for a set of interest rates $\{y_1, \dots, y\}$ to be in the core. These are not sufficient (nor are they the focus of our empirical analysis in the paper).

1. Individual rationality requires that $y_i \omega_i \geq \nu(\{i\})$. That is: $y_i \geq d$ if $\omega_i > 0$ and $y_i \leq b$ if $\omega_i < 0$.
2. Similarly, $\sum_{j \in N \setminus \{i\}} y_j \omega_j \geq \nu(N \setminus \{i\})$ implies the following: if $\omega_i > 0$ then $\sum_{j \in N \setminus \{i\}} \omega_j = \sum_{j \in N} \omega_j - \omega_i = 0 - \omega_i < 0$. Therefore, $\nu(N \setminus \{i\}) = -b\omega_i$. Hence,

$$0 - y_i \omega_i = \sum_{j \in N \setminus \{i\}} y_j \omega_j \geq \nu(N \setminus \{i\}) = -b\omega_i,$$

which implies that $y_i \leq b$.

$$(2) \quad b \geq y_i \geq d.$$

A similar argument implies that $b \geq y_i \geq d$ when $\omega_i < 0$.

Conditions (2) are necessary for an allocation to be in the core: they simply say that actual payoffs must lie inside the “corridor” bank rates imposed by the central bank. The conditions are not sufficient.

3. For a general coalition S , we require that

$$(3) \quad \begin{aligned} \sum_{i \in S} y_i \omega_i &\geq d \sum_{i \in S} \omega_i, & \text{for } \sum_{i \in S} \omega_i > 0 \\ \sum_{i \in S} y_i \omega_i &\geq b \sum_{i \in S} \omega_i, & \text{for } \sum_{i \in S} \omega_i < 0. \end{aligned}$$

In the second inequality above, because $b > 0$ (as is typically the case), the right-hand side of the inequality is negative. These two inequalities embody the intuition that a coalition which is collectively a net lender (resp. borrower) must obtain a higher payoff than lending to (resp. borrowing from) the central bank.

4. Finally, when $\sum_{i \in S} \omega_i = 0$ we need to impose that $\sum_{i \in S} y_i \omega_i \geq 0$. This just means that a coalition in which the members' balances cancel out should not be making a negative payoff.

Note that it would be incorrect to simply check conditions (2), as they ignore what is achievable by general coalitions of banks in the system. We focus in this paper on the full consequences of core stability (or efficiency), not only on whether interest rates are in the band defined by the central bank.

3.2 A measure of bargaining power λ

It is easy to check that the vectors of rates (d, \dots, d) and (b, \dots, b) are both in the core.¹³ The first is the best allocation for the debtors and the second is the best allocation for the creditors. All the allocations $\lambda(b, \dots, b) + (1 - \lambda)(d, \dots, d)$ for $\lambda \in (0, 1)$ are in the core as well. *In fact, when the allocation lies on this line, or close to it, then we can interpret λ as a measure of bargaining power for the creditors.* When $\lambda \sim 1$ we obtain the core allocations that are best for the creditors; note that in this case the creditors are obtaining a deal which is similar to the “take it or leave it” offer of the central bank. It makes sense to interpret such an allocation as reflective of a high bargaining power on the side of creditors. Similarly, when $\lambda \sim 0$ we obtain the core allocations that are best for the borrowers. In this case, they are getting a similar deal to the one obtained by the central bank in

¹³Thus, the core is always non-empty. A necessary and sufficient condition for the non-emptiness of the core is that the game be balanced. A basic exposition of the theory is in Osborne and Rubinstein (1994).

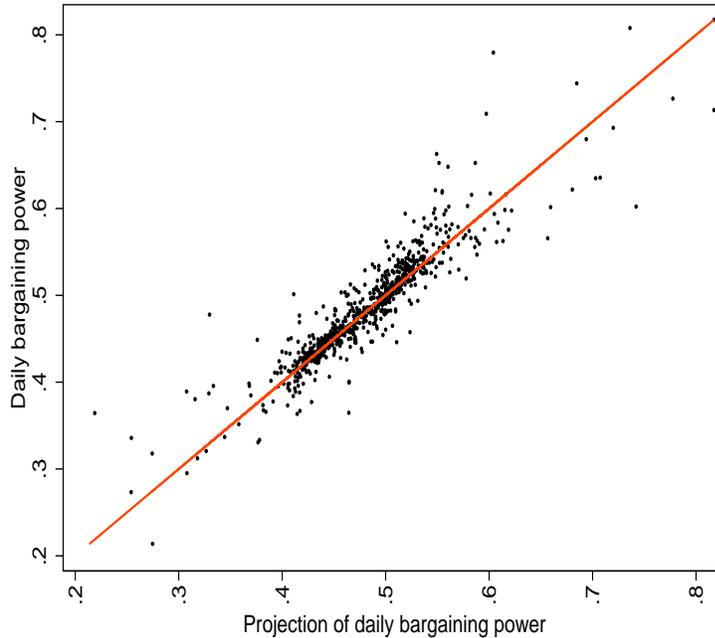


Figure 4: Goodness of Fit

its role as borrower.¹⁴ As Figure 4 illustrates, λ provides a reasonable measure of bargaining power for the LVTS trades. In that figure, we plot (on the y-axis) the actual interest rates received by the LVTS participants, versus (on the x-axis) the linear projection of this rate on the line segment between (b, b, \dots, b) and (d, d, \dots, d) . That is, for the interest rate y_{it} received by bank i on date t , the projected rate is $\hat{y}_{it} = \hat{\lambda}_t * b + (1 - \hat{\lambda}_t) * d$ where $\hat{\lambda}_t$ denotes the bargaining power measure estimated for day t . (Note that the projected rate \hat{y}_{it} is the same for all banks i trading on day t , because λ_t does not vary across banks.) Figure 4 shows that, for the vast majority of trades, the projected rate is close to the actual rate. This provides reassurance that λ_t serves as an adequate measure of bargaining power for this market. ■

¹⁴An alternative would be to look at bilateral interest rates on individual loans, and gauge bargaining power depending on whether the lender or the borrower gets a better deal. Our measure represents a way of aggregating up to a daily market-wide measure. It looks at the market outcome, and sees if it is closer to the best outcome for lenders or borrowers.

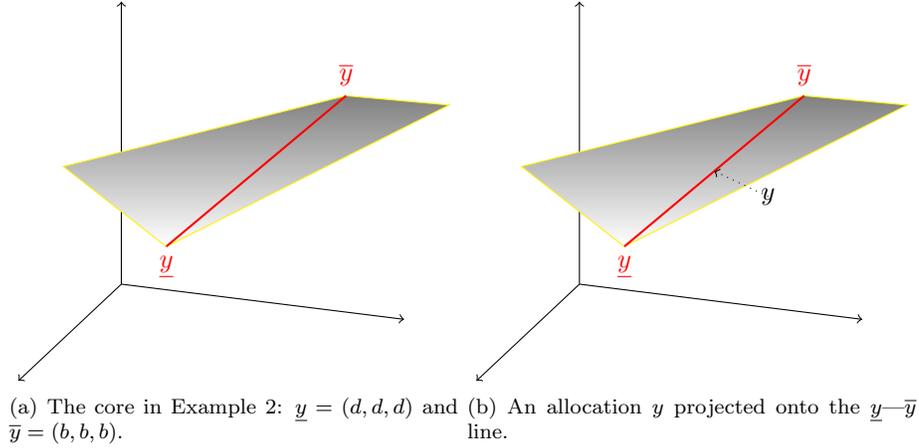


Figure 5: An illustration of Example 2.

3.3 The Core of the Interbank Market: some examples

Next, we provide several examples of the core of markets.

Example 1: Suppose that $|\omega_i| = 1$ for all i . Then if $\omega_i = 1$ and $\omega_j = -1$ we require $y_i - y_j \geq 0$, as $\nu(\{i, j\}) = 0$. Similarly, reasoning from $N \setminus \{i, j\}$ we get $y_i - y_j \leq 0$, so $y_i - y_j = 0$. Then the core is exactly the allocations $\lambda * (b, \dots, b) + (1 - \lambda) * (d, \dots, d)$, for $\lambda \in (0, 1)$. ■

Example 2: Suppose that there are three agents, and that the agents' net positions are $(\omega_1, \omega_2, \omega_3) = (-1, -1, 2)$. The core is the set of points (y_1, y_2, y_3) that satisfy the core constraints. First, no individual agent must be able to block a core allocation, hence all the points in the core are in $[d, b]^3$. Second, we obtain that $2y_3 - y_1 \geq d$ and $2y_3 - y_2 \geq d$ for coalitions $\{1, 3\}$ and $\{2, 3\}$, respectively. Finally, the coalition of the whole requires that $-y_1 - y_2 + 2y_3 = 0$. The latter condition, together with $(y_1, y_2, y_3) \in [d, b]^3$, imply the conditions for coalitions $\{1, 3\}$ and $\{2, 3\}$. Thus the inequalities $2y_3 - y_1 \geq d$ and $2y_3 - y_2 \geq d$ are redundant.

We illustrate the core in Figure 5. Allocations are points in \mathfrak{R}^3 , as there are three agents in the example. The shaded region is the set of points that satisfy the core constraints. Geometrically, it consists of the points on the plane $-y_1 - y_2 + 2y_3 = 0$ that have all their coordinates larger than d and smaller than b . The half-line $\lambda(b, b, b) + (1 - \lambda)(d, d, d)$ is indicated in red in the figure and is

Table 1: Sample trades

Borrower	Lender	Amount	Interest Rate(rel. to target rate)
B	E	1.00	-0.0077
E	K	1.29	-0.0581
K	A	1.00	0.0022

Table 2: Banks positions and prices

Bank	ω	y
A	1.00	0.0022
B	-1.00	-0.0077
E	-0.29	-0.2319
K	0.29	-0.2660

a proper subset of the core. There are then core allocations, such as $(b, d, (b + d)/2)$, which are not symmetric.

Figure 5(b) also illustrates how we calculate bargaining power. A point y is projected onto the line $\lambda(b, b, b) + (1 - \lambda)(d, d, d)$. The value of λ corresponding to the projection is a measure of the bargaining power of the creditors in the bargaining process that resulted in the allocation y . ■

Example 3: Finally, we consider one illustrative example of an actual allocation from the LVTS. On this particular day, there were four banks (labeled A,B,E,K) involved, and a total of three trades. Because we have normalized the target rate to zero, the values of (b, d) are $(0.25, -0.25)$.

Based on these trades, we can construct the bank-specific balances and prices (ω_i, y_i) . For concreteness, consider bank E, which is both a lender (to B) and a borrower (from K). The value of ω for E is just its net position, which is $-0.29 = 1 - 1.29$. Correspondingly, its price y is the trade-weighted interest rate:

$$y_E = \frac{(1.0) * (-0.0077) + (-1.29) * (-0.0581)}{1 - 1.29} = -0.2319.$$

Similarly, Table 2 contains the positions and prices for all four banks.

For these four banks, there are $2^4 - 1 = 15$ coalitions to check. The different possible coalitions are listed in Table 3 along with whether they satisfy the core inequalities defined in section 3 above.

Table 3: Inequalities

Coalition	Satisfies inequalities?
$\{A, B, E, K\}$	Yes
$\{B, E, K\}$	Yes
$\{A\}$	Yes
$\{A, E, K\}$	Yes
$\{B\}$	Yes
$\{A, B, E\}$	Yes
$\{K\}$	No
$\{A, B, K\}$	Yes
$\{E\}$	Yes
$\{B, E\}$	Yes
$\{A, K\}$	Yes
$\{E, K\}$	No
$\{A, B\}$	Yes
$\{A, E\}$	Yes
$\{B, K\}$	Yes

First, note that, by construction, $\sum_{i=A,B,E,K} \omega_i = 0$ and $\sum_{i=A,B,E,K} y_i \omega_i = 0$. Second, we can see by examining the positions in Table 1 for the reasons that the three coalitions fail to satisfy the inequalities. In the data, bank K is a net lender of 0.29, at a price of -0.2660, which is lower than the rate of $d = -0.25$ it could have obtained by depositing the net amount of 0.29 at the Bank of Canada. Also, the coalition of $\{E, K\}$ has a net zero balance, but a payoff of $\sum_{i=E,K} \omega_i y_i = 0.29 * (0.2319 - 0.2660) < 0$, which is negative. They could have done better if K had not lent the amount of 0.29 to E at any rate, in which case their payoff would have been zero.

On the other hand, consider the coalition $\{A, B, E\}$, with a net position of $\sum_{i=A,B,E} \omega_i = -0.29$. The payoff for this coalition at the observed allocation is $\sum_{i=A,B,E} \omega_i y_i = 0.0771$ which exceeds $b * (-0.29) = -0.0725$. That is, on net, this coalition, despite having a negative net balance, obtains a positive net payoff, which is of course preferable to borrowing 0.29 from the Bank of Canada at the rate $b = 0.25$. This also implies that the banks who are lending to the the coalition $\{A, B, E\}$ – here it is just bank K – must be receiving too little; this is indeed the case, as the singleton coalition $\{K\}$ violates the inequalities. ■

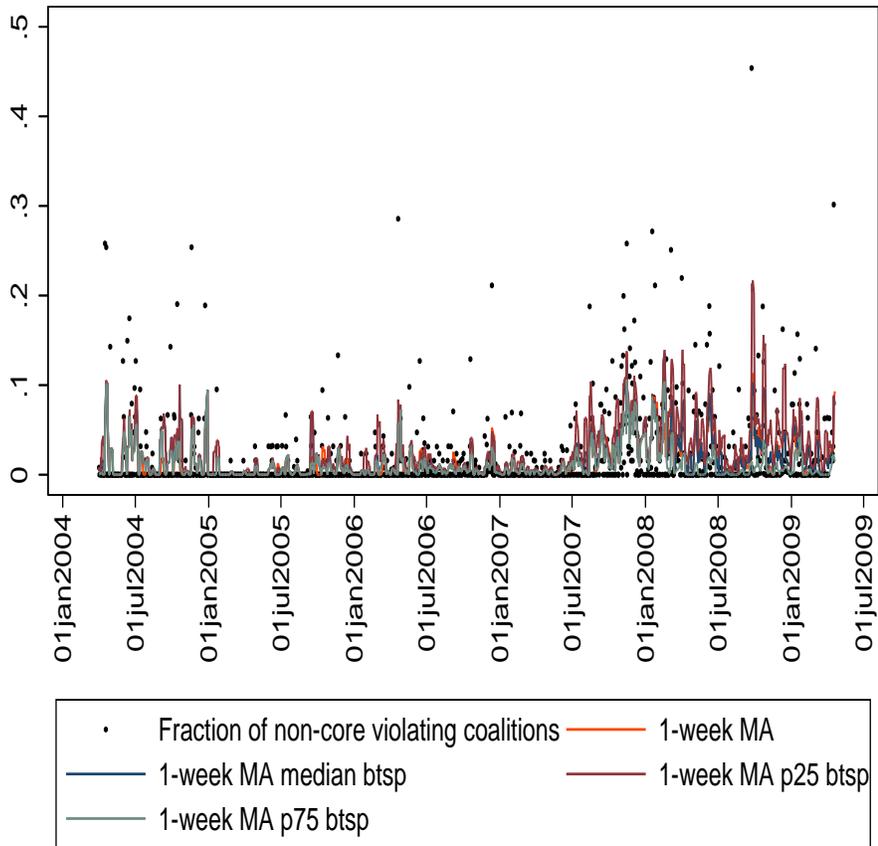


Figure 6: Fraction of non-core violating coalitions

4 Empirical results

In the dataset, we observe (ω_{it}, y_{it}) for banks $i = 1, \dots, n$ and days $t = 1, \dots, T$. This corresponds to the outstanding balance at bank i at the end of day t and the interest rate that bank i either paid ($\omega_{it} < 0$) or earned ($\omega_{it} > 0$) by borrowing or lending in LVTS. Given the prices and quantities from LVTS, our approach allows us to solve for the percentage of transactions that are violations of *core* (denoted by av), as well as the bargaining power (λ) of lenders relative to borrowers on each day.

4.1 Interbank Market Efficiency: Are Trades in the Core?

Necessary conditions for the day t settlement interest rates $\{y_{it}\}_{i=1}^n$ to be in the core of the game are the inequalities (2) and (3) sketched above. Figure 6 plots the degree to which each day's allocation violates the core inequalities. It presents a plot of the percent of coalitions on each day that violate the core inequalities. The figure also includes a one-week moving average representation of the violations and one-week moving averages of the violations allowing for the price data to be miss-classified. The recent literature on implementation of the Furfine algorithm suggests that payments could be miss-classified as loans. In these cases we would over-estimate the degree of core violations. We therefore introduce type 1 error when sampling the loans (see Rempel (2014)).

The approach requires constructing synthetic non-loan payments along with the uniquely identified loans. The synthetic payments are randomly paired payments that look like the output from the Furfine algorithm but are not constrained by the chronological order of payment/repayment dates or interest rate filter. The original loan data is then augmented with the false loans before we resample from the augmented data to create bootstrap samples of Furfine loans.

On most days the vast majority of overnight loans do not violate our core equilibrium restrictions and are therefore deemed efficient. However, on approximately 46 per cent of days there is at least one core restriction that is violated: at least one coalition could do better by trading among themselves. There are only 19.8 per cent of days where more than 10 per cent of trades violate the core inequality restrictions. The percent of inefficient coalitions, however, increases in the fall of 2007 and throughout most of 2008.

Since, as we emphasized above, the core restrictions are essentially no-arbitrage conditions imposed on coalitions of banks, one way to quantify the severity of the violations is to compute how much a coalition could gain if it were to deviate from the observed allocation, thereby exploiting the arbitrage opportunity implied by the violation of the core inequalities. If the gain is small it might not be worthwhile for lenders and borrowers to negotiate a better allocation. We can think of the gain as the distance of the allocation to the core, or as the *cost* of the bargaining outcome relative to full efficiency. We calculate the cost by measuring the distance between the allocation x at any give date and the closest core allocation. To determine this distance we need to solve the problem of minimizing $\|x - z\|$, which is the Euclidean distance between the observed allocation x and any

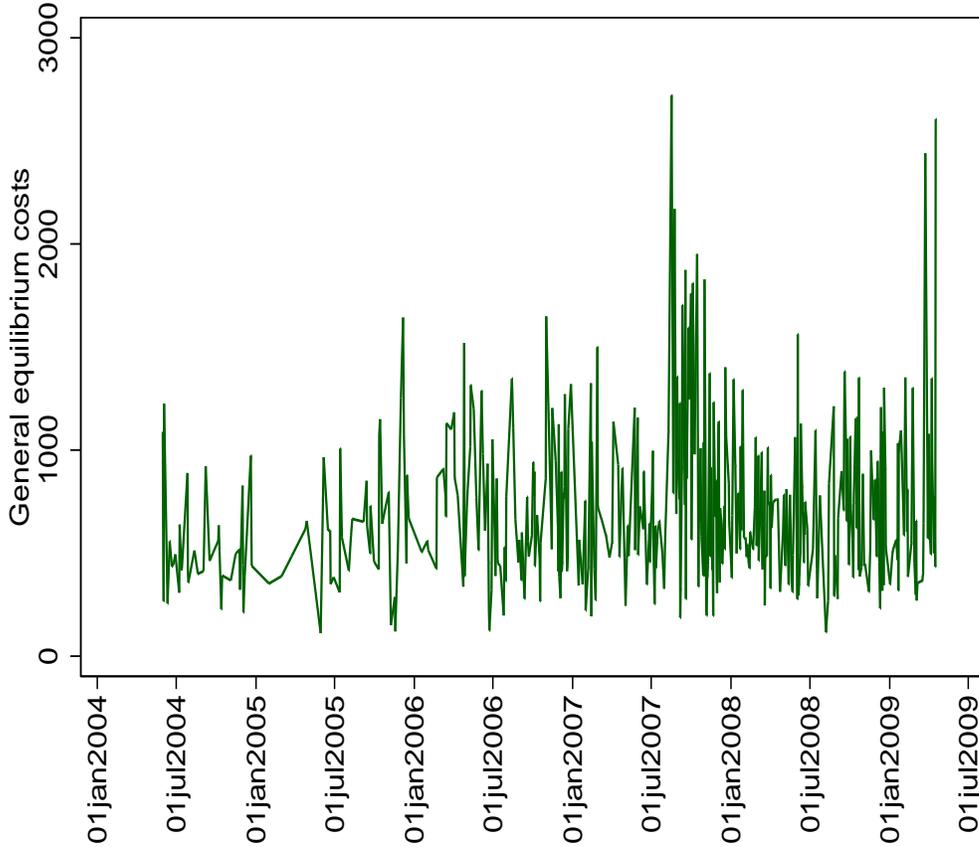


Figure 7: Costs of Overnight Loan Outside the Core

alternative allocation z which lies within the core.

The overnight costs are plotted in Figure 7. The average cost of correcting a violating allocation is \$698 and the maximum is \$2720. These costs are larger than those presented elsewhere, eg. in Chapman, McAdams, and Paarsch (2007).¹⁵ To give some context, note that the dollar value of these costs translates roughly to two basis points.¹⁶ While at first glance this may seem small

¹⁵Chapman, McAdams, and Paarsch (2007) studies the bidding behavior of these same participants in daily 4:30pm auctions for overnight cash, and find that, while there are persistent violations of best-response functions in these auctions, the average cost of these violations is very small, only a couple of dollars.

¹⁶This is found by multiplying the average number of trades by the average loan size and finding the dollar cost of one basis point for this amount.

when compared to other, more volatile, markets, it is actually large in this instance where the standard deviation of the overnight rate around the overnight target is one basis point. Therefore, our estimates suggest that the expected costs due to inefficiency dwarf the expected risk in this market.¹⁷

4.2 Bargaining Power

We construct a measure of bargaining power for lenders relative to borrowers for each day, and then evaluate how it evolves over time. Specifically, we project each daily allocation onto the line $\lambda(b, \dots, b) + (1 - \lambda)(d, \dots, d)$. This gives us an estimate of λ for each day. In addition, we construct measures of bargaining power for different sub-samples of the Furfine data. The recent literature on implementation of the Furfine algorithm and associated miss-classification error, implies that our estimate of bargaining power can be measured with error. As we did with the efficiency measure, we borrow from Rempel (2014) and model the distribution of type 1 error in the classification of payments into loans.

Figure 8 plots the bargaining power of the lenders using four different draws from the Furfine data. The median spline is based on the original draw, assuming no type 1 error; we also include the median spline based on the twenty-fifth, median, and seventy-fifth percentile of the resampled distribution. Both the median spline on the original data and subsampled data are nearly identical. The 25th and 75th percentiles are nearly identical in the first two sub-periods with some deviation in the financial crisis.

When λ equals 1 the lender has all the bargaining power and when it is 0 the borrower has all the bargaining power. The bargaining power of lenders and borrowers is roughly equal between April 2004 and January 2006. Then it moves in favor of lenders until January 2008. Lenders' bargaining power is the greatest from August to October of 2007 following the closure of two hedge funds on August 9, 2007 by BNP Paribas and statements by several central banks, including the Bank of Canada, that they would inject overnight liquidity.¹⁸ Starting in January 2008 the bargaining power

¹⁷It is possible that since the participants in LVTS also trade on behalf of clients that it is easier to pass these costs on to them than improve the allocation and be inside the core.

¹⁸On August 9th, 2007 the Bank of Canada issued a statement that they were ready to provide liquidity. The ECB

of borrowers is greater than that of the lenders. We analyze the determinants of bargaining power in section 4.3.

4.3 Regression Results

This section explores how core violations and $(1 - \lambda)$, i.e., the borrowers' bargaining power, are correlated with bank and LVTS characteristics. We also analyze how costs are related to violations and bargaining power.

4.3.1 Explanatory Variables

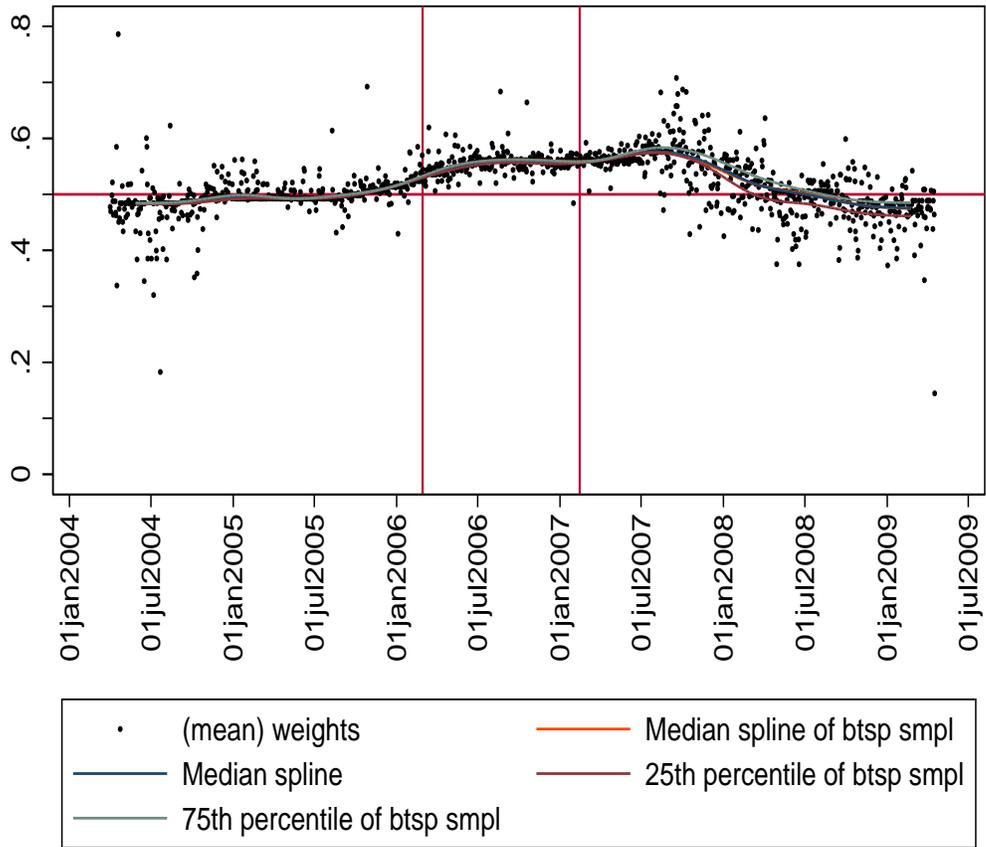
Table 4 presents summary statistics of our variables of interest and explanatory variables for three sub-samples: (i) April 1, 2004 to February 28, 2006, (ii) March 1, 2006 to February 14, 2007, and (iii) February 15, 2007 to April 20, 2009. The samples are chosen based on important demarcations of events. April 1, 2004 is when our sample begins. The final sample date, April 20, 2009, was chosen because it is the day before the Bank of Canada instituted an interest rate policy at the effective lower bound, making analysis after this day more complicated. From March 1, 2006 to February 14, 2007, the Bank of Canada targeted cash settlement balances to be zero, i.e. did not injecting liquidity (Reid 2007). Finally, our crisis period starts February 15, 2007 as the Bank of Canada abandoned its zero balance target to compensate for the increasing demand for liquidity.

In our analysis an observation is a day, and includes all transactions from 5:00pm to 6:30pm. On the average day there are 8.8 loans, involving 5.7 borrowers and 4.4 lenders. In over 95% of cases there are more than 3 borrowers trading on a particular day.

Our analysis includes bank risk measures such as credit default swap (CDS) spreads, Merton's (1974) distance-to-default (DD), and funding risk defined as wholesale funding over total assets (WF/TA).¹⁹ DD measures the market value of a financial institutions assets relative to the book value of its liabilities. An increase in DD means a bank is less likely to default. Further-

injected €95 billion overnight.

¹⁹Liquidity is defined as cash and cash equivalents plus deposits with regulated financial institutions, less allowance for impairment, therefore illiquid assets are the majority of the balance sheet and include loans, securities, land, etc. Wholesale funding is defined as fixed term and demand deposits by deposit-taking institutions plus banker acceptances plus repos. Total funding also includes wholesale funding plus retail deposits and retained earnings.



NOTE: The first vertical line is at February 28, 2006 and the second line is February 14, 2007. April 1, 2004 until February 28, 2006 corresponds to a normal period. Between February 28, 2006 and February 14, 2007 the Bank of Canada targeted zero cash settlement balances. The third period is February 15, 2007 to April 20, 2009. The horizontal line is when lenders and borrowers have equal bargaining power.

Figure 8: Bargaining Power of the Lender

more, institutions with high wholesale funding ratios are considered more risky. We also include an indicator variable for whether or not a financial institution accessed the Bank of Canada’s term liquidity facility during the crisis (see Allen, Hortaçsu, and Kastl 2011), or the Canadian government’s Insured Mortgage Purchase Program (IMPP).²⁰

Market trend or risk variables include the spread between the one month Canadian Dealer Offered Rate and one month Overnight Indexed Swap rate ($CDOR - OIS$), total number of lenders, borrowers and trades in LVTS on each day, and cash settlement balances in LVTS (central bank liquidity). The one month $CDOR$ is similar to one month $LIBOR$ in that it is indicative of what rate surveyed banks are willing to lend to other banks for one month. OIS is an overnight rate and is based on expectations of the Bank of Canada’s overnight target rate. The spread is a default risk premium. We interpret increases in the $CDOR - OIS$ spread as increases in default risk of the banking industry generally and not related to any specific institution as DD, CDS, or WF/A measurements are.

As discussed in section 2.2, cash settlement balances are important since they are actively managed by the Bank of Canada. To manage minor frictions and offset transactions costs the Bank typically leaves excess balances of \$25 million in the system. Figure 3 shows this to be the case. The figure also shows that balances can be negative (that is, the Bank of Canada left the system short), which they were 15 times between March 2006 and February 2007. Figure 3 also shows that the Bank injected liquidity substantially above \$25 million for almost the entire time between the summer of 2007 and early 2009.

4.3.2 Determinants of Violations of Core Inequalities

We consider a Poisson regression for the percent of violations in a day and a Probit regression for whether or not there was a violation on a given day. We interact all of the covariates with indicator variables for three sub-samples, where an observation is a day in one of the following periods: (i) April 1, 2004 to February 28, 2006, (ii) March 1, 2006 to February 14, 2007, and (iii) February 15,

²⁰The IMPP is a government of Canada mortgage buy-back program aimed at adding liquidity to banks’ balance sheets. On October 16, 2008 the government announced it would buy up to \$25 billion of insured mortgages from Canadian banks. This represented about 8.5% of the banking sectors on-balance sheet insured mortgages. On November 12, 2008 this was raised to \$75 billion, and subsequently raised to \$125 billion on January 28, 2009.

Table 4: Summary Statistics

Variable	Pre-crisis			Zero target			Crisis		
	Mean	SD	N	Mean	SD	N	Mean	SD	N
λ (bargaining power of lender)	0.496	0.038	476	0.556	0.020	242	0.521	0.057	543
av (% of violations)	0.966	3.2	476	0.988	2.86	242	2.6	4.84	543
av_2 (% of violations $ av \neq 0$)	5.41	5.79	85	2.65	4.19	91	5.11	5.76	276
Loan amount (in millions)	173.18	68.30	476	191.0	52.62	242	196	60.9	543
Hour sent	5:25pm	21mins	476	5:31pm	15mins	242	5:30pm	15mins	543
Spread to target	-0.002	0.018	476	0.028	0.009	242	0.008	0.028	543
Cash settlement balances (in 100 million)	0.643	0.650	476	0.057	1.71	242	1.37	2.94	543
Number of borrowers	3.84	1.45	476	6.0	1.66	242	5.8	1.51	543
Number of lenders	3.18	1.29	476	3.96	1.53	242	4.33	1.43	543
Number of trades	5.39	2.31	476	8.71	2.87	242	8.79	2.62	543
Average coalitions per day	771	6,264	476	4,851	13,632	242	3,551	7,716	543
$CDOR_1 - OIS_1$	0.054	0.028	476	0.101	0.026	242	0.243	0.212	543
Distance to default	7.20	0.58	476	7.21	0.39	242	4.46	2.24	543
Wholesale funding/assets	0.236	0.025	476	0.268	0.025	242	0.315	0.077	543
CDS	13.21	0.95	123	10.76	0.70	242	68.7	49.3	543

Notes: These are summary statistics for loans of 50 million dollar and above at or after 5:00pm. The pre-crisis sample is Apr 1, '04-Feb 28, '06; the zero target sample is Mar 1, 2006-Feb 14, 2007 and the crisis sample is Feb 15, 2007- Apr 20, 2009.

2007 to April 20, 2009.

The explanatory variables used to explain violations of the core restrictions (equations (2) and (3)) are at the market level. We include $CDOR - OIS$, as well as the number of borrowers, lenders, and trades. We also include actual cash settlement balances in the system.²¹ The results are presented in Table 5. The percentage of violations we observe in the data are decreasing in the $CDOR - OIS$ spread except in the crisis period where it is increasing (the difference is statistically significant). This finding is reasonable as it suggests that in normal times multilateral bargaining becomes more focused as market risk increases and therefore it is more likely that the bargaining mechanism results in an efficient outcome. During a crisis, however, we notice an increase in inefficient outcomes and in particular as market risk increases so do the violations. In combination with the findings below on bargaining power shifting towards *borrowers* during the crisis, this result suggests that some banks were willing to make inefficient trades during the crisis in order to “shore up” troubled banks.

²¹In regressions not reported here we also analyzed the importance of operational risk. This risk includes the occasional system failure due to process, human error, etc. Operational risk also excludes 6 days where the trading period was extended beyond 6:30pm. The average extension was 45 minutes. Internal operational risk measures were not significant in explaining core violations or bargaining power.

We also find that violations are increasing in the number of participants. The more players involved in the game (especially lenders), the greater the percentage of violations, which suggests there is more likely to be an inefficient outcome when a larger group tries to negotiate than when there is a smaller group. Finally, we find that liquidity injections by the central bank (actual LVTS cash balances) is correlated with an increase in core violations. Statistically the effects of liquidity on core violations are the same across all sub-periods. This fact suggests that the effect of liquidity on multilateral bargaining is not the result of the crisis but from the liquidity injections themselves.²² Liquidity injections, therefore, appear to increase the number of inefficient allocations. Consistent with Goodfriend and King (1988), the financial market is efficient at allocating credit without the central bank holding large cash settlement balances. The result is also consistent with the stylized fact presented in Bech and Monnet (2013) that market volume (trades) falls when there is excess liquidity. We find that both inefficiency falls when trading increases and that inefficiencies increase when the central bank adds liquidity. Central bank liquidity discourages trading, which is what leads to the increase in inefficient outcomes.

4.3.3 Determinants of Bargaining Power

For bargaining power we estimate the linear time-series regression on daily observations:

$$(4) \quad (1 - \lambda)_t = \alpha + \rho(1 - \lambda)_{t-1} + \beta \bar{X}_{1t} + \gamma X_{2t} + \xi_t + \epsilon_t,$$

where we include in X the number of lenders and borrowers, total number of transactions, actual LVTS cash settlement balances in the system (liquidity injections), and one month $CDOR - OIS$ spread. We also include asset-weighted averages of the following in \bar{X} for those borrowing on day t . This includes distance-to-default, CDS spreads, and the ratio of wholesale funding to assets at

²²This is somewhat in contrast to Freixas, Martin, and Skeie (2012) who show that a central bank which controls both the level of the interbank rate and the amount of liquidity injected can achieve efficiency in the interbank market. Our empirical results imply that regardless of what level (i.e. when it is constant and decreasing) the interbank rate is, increasing liquidity decreases efficiency. That is, we not only find a correlation between liquidity injections (high cash settlement balances) and the percentage of core violations during the crisis, but also during the first pre-crisis sub-period, when the Bank of Canada was actively injecting liquidity into the interbank market.

month $m - 1$. We also include indicator variables equal to 1 if a bank accessed the Bank of Canada liquidity facility (term PRA) or sold mortgages for cash via the IMPP program. Finally, we include borrower fixed effects since the balance-sheet data is monthly and the bargaining power data is daily.

Table 6 presents estimates of the regression, broken down by the three sub-samples given the heterogeneity in the estimated impacts on core violations as reported in Table 5 above. Striking contrasts across sub-periods emerge in these specifications – especially during the financial crisis period. In the first “normal” period, 2004-2006 only CDS out of all the bank-level risk factors appear to be priced. This is a period where bargaining power is almost always split evenly between borrowers and lenders with little variation and CDS prices are not available for all institutions. The main risk factor is market risk, i.e. the CDOR-OIS spread. In the zero cash balance period we see an increase in bargaining power towards lenders and bank-level risk factors being priced and market risk turning insignificant. The coefficients attached to the risk measures suggest that riskier institutions enjoy less bargaining power. However, during the financial crisis period (post-2007), bargaining power becomes *negatively* correlated with distance-to-default and *positively* correlated with CDS spreads. The results on wholesale funding exposure go from large and negatively correlated to uncorrelated, suggesting a disconnect between risk and bargaining power. Thus riskier institutions enjoyed more bargaining power during these troubled times.

What are possible explanations? One possibility is that mark-to-market accounting and bank interconnectedness means that some banks were concerned with their positions vis-à-vis the riskier banks (e.g. Bond and Leitner 2010). The short-term cost of lending to a risky bank at a discount to an interconnected bank might be far less than the cost of having to mark down assets linked to a failed institution. A second reason is the OTC market features repeated interactions among players who know that liquidity might be fleeting. Carlin et al. (2007), for example, present a model of episodic liquidity in which repeated interaction sustains firms’ provision of “apparent liquidity” to each other.

At the same time, the risk that any Canadian bank would fail is extremely minute; this is evidenced by the small CDS spreads, which were only 69 bp on average even during the crisis. An alternative explanation, therefore, for our results may simply be reflecting differences in liquidity needs across banks: during the crisis, the Bank of Canada added liquidity to the market, which

lowered the price of liquidity and disproportionately attracted riskier borrowers. This possibility would also lead to the positive association between borrowers' default risk and their bargaining power during the crisis period, which we find in our results. However, we see that "Actual LVTS settlements", which measures the Bank of Canada's liquidity injections, is always insignificant in the regressions in Table 6; casting doubt on this explanation.

Finally, the summary statistics from the sub-periods suggests there is not a great deal of change in persistence over time. Overall the lack of any significant change in the transition probabilities suggests that bargaining power increased for borrowers in general, and not for any particular set of borrowers. A careful look at the bank-level transition probabilities, not presented here, does not reveal overwhelming evidence to suggest any particular borrower received preferential treatment.

Table 5: Regressions on Violations of Core Inequality Restrictions

The dependent variable in column (1) is av , which is the percentage of violations of the core restrictions per day. The unit of observation is therefore a day. The dependent variable in column (2) is $I(av \neq 0)$ therefore this specification is estimated by Probit. The three time periods are the baseline (i) Non-crisis (April 1, 2004-February 28, 2006) and (ii) zero target (March 1, 2006-February 14, 2007, i.e. the period where the Bank of Canada targeted a zero cash balance in LVTS) and (iii) Crisis (February 15, 2007-April 20, 2009). The 1 month CDOR-OIS spread is the difference between the Canadian Dealer Offered Rate and one month Overnight Indexed Swap rate, where the former is the rate surveyed banks are willing to lend to other banks for one month and the latter is an over-the-counter agreement to swap, for one month, a fixed interest rate for a floating rate. “Actual LVTS cash balances” is the actual amount of liquidity in the payments system (in 100 million CAD); high balances means more central bank liquidity injections. Standard errors are in parentheses and are clustered at the borrower level. ^a $p < 0.01$, ^b $p < 0.05$, ^c $p < 0.1$.

VARIABLES	(1) Percent of core violations	(2) Violations (Y/N)
Lagged violations*I(t=normal)	0.0746 ^a (0.00773)	0.0455 ^c (0.0253)
Lagged violations*I(t=zero target)	-0.00865 (0.0279)	-0.00718 (0.0336)
Lagged violations*I(t=crisis)	0.0238 ^a (0.00456)	0.0157 (0.0113)
1 month CDOR-OIS*I(t=normal)	-23.50 ^a (2.378)	-1.250 (4.186)
1 month CDOR-OIS*I(t=zero target)	-7.997 ^b (3.292)	0.376 (4.048)
1 month CDOR-OIS*I(t=crisis)	0.655 ^a (0.160)	0.675 ^c (0.368)
Number of lenders*I(t=normal)	0.302 ^a (0.0579)	0.182 (0.125)
Number of lenders*I(t=zero target)	0.464 ^a (0.0644)	0.235 ^b (0.0967)
Number of lenders*I(t=crisis)	0.132 ^a (0.0252)	0.0737 (0.0574)
Number of borrowers*I(t=normal)	-0.168 ^a (0.0608)	-0.110 (0.127)
Number of borrowers*I(t=zero target)	0.00837 (0.0628)	0.0638 (0.0952)
Number of borrowers*I(t=crisis)	0.0501 ^c (0.0269)	0.127 ^b (0.0612)
Number of trades*I(t=normal)	-0.0460 (0.0515)	0.103 (0.0997)
Number of trades*I(t=zero target)	-0.226 ^a (0.0492)	0.0114 (0.0712)
Number of trades*I(t=crisis)	-0.0308 ^c (0.0187)	-0.0281 (0.0425)
Actual LVTS cash balances*I(t=normal)	0.0979 ^b (0.0498)	0.0567 (0.119)
Actual LVTS cash balances*I(t=zero target)	0.0574 ^b (0.0255)	-0.00462 (0.0517)
Actual LVTS cash balances*I(t=crisis)	0.0525 ^a (0.00687)	0.0197 (0.0193)
Constant	0.736 ^a (0.175)	-2.539 ^a (0.417)
Observations	31 1260	1260

Table 6: Bargaining Regressions

The dependent variable is $100 * (1 - \lambda)$, i.e. the bargaining power of the borrowers. A unit of observation is a day, therefore balance sheet variables and risk measures are averages of borrowers on each day. Percentage of core violations (av) is defined as the percentage of transactions that are violations of the *core*. "Actual LVTS cash balances" is the actual amount of liquidity in the payments system (in 100 million CAD); high balances means more central bank liquidity injections. The 1 month CDOR-OIS spread is the difference between the Canadian Dealer Offered Rate and one month Overnight Indexed Swap rate, where the former is the rate surveyed banks are willing to lend to other banks for one month and the latter is an over-the-counter agreement to swap, for one month, a fixed interest rate for a floating rate. $I(\text{Term PRA allocation at } t - 1 > 0)$ is an indicator variable for whether or not a borrower accessed short-term liquidity in the Bank of Canada repo auctions, which became available in 2007; $I(\text{IMPP allocation at } t - 1 > 0)$ is an indicator variable for whether or not a borrower accessed short-term liquidity in the Canadian government mortgage liquidity program, which became available in 2008. Distance to default is based on Merton's (1974) model. A firm is considered in default if its value falls below its debt. High values of distance to default imply a bank is less likely to default. Wholesale funding is defined as fixed term and demand deposits by deposit-taking institutions plus banker acceptances plus repos. Wholesale funding as a fraction of assets is a banks' exposure to risky short-term funding. CDS is a borrowers' credit default swap spread – higher spreads indicate higher risk of default. All specifications include borrower fixed effects. Standard errors are in parentheses and are clustered at the borrower level. a $p < 0.01$, b $p < 0.05$, c $p < 0.1$.

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Pre-crisis			Zero target			Crisis		
$(1-\lambda)_{t-1}$	0.0321 (0.0870)	0.00130 (0.0864)	0.00278 (0.0875)	0.0745 (0.0621)	0.128 ^b (0.0640)	0.0740 (0.0627)	0.143 ^a (0.0462)	0.216 ^a (0.0463)	0.143 ^a (0.0463)
Percent of core violations	-0.0570 (0.198)	-0.0560 (0.194)	-0.0558 (0.195)	-0.187 ^a (0.0637)	-0.189 ^a (0.0639)	-0.191 ^a (0.0628)	0.165 ^c (0.0871)	0.165 ^c (0.0863)	0.165 ^c (0.0869)
Number of lenders each day	-0.0595 (0.188)	-0.0282 (0.187)	-0.0203 (0.188)	0.212 ^c (0.124)	0.145 (0.123)	0.216 ^c (0.125)	-0.145 (0.175)	-0.129 (0.181)	-0.146 (0.175)
Number of borrowers each day	0.662 (1.343)	0.598 (1.310)	0.682 (1.286)	-1.360 ^a (0.438)	-1.327 ^a (0.377)	-1.372 ^a (0.445)	0.108 (0.521)	0.168 (0.534)	0.109 (0.522)
Number of trades each day	-0.0351 (0.135)	-0.0130 (0.135)	-0.0134 (0.135)	0.0672 (0.0853)	0.0969 (0.0834)	0.0619 (0.0861)	0.111 (0.142)	0.0567 (0.144)	0.112 (0.143)
Actual LVTS settlements (100 millions)	0.165 (0.214)	0.0546 (0.193)	0.0460 (0.195)	0.114 ^a (0.0417)	0.0979 ^b (0.0453)	0.114 ^a (0.0429)	-0.0519 (0.101)	-0.0447 (0.105)	-0.0522 (0.101)
1 month CDOR minus 1 month OIS	-22.16 ^a (7.443)	-15.67 ^b (6.338)	-15.57 ^b (6.332)	5.624 (3.945)	6.116 (4.009)	5.114 (3.989)	-3.212 ^b (1.363)	-3.784 ^b (1.481)	-3.168 ^b (1.357)
$I(\text{Term PRA allocation at } t-1 > 0)$							0.0188 (0.711)	0.129 (0.742)	0.0238 (0.712)
$I(\text{IMPP allocation at } t-1 > 0)$							-0.466 (1.427)	-0.367 (1.272)	-0.456 (1.446)
Distance to default	0.260 (0.418)		0.325 (0.412)	1.426 ^a (0.422)		1.376 ^a (0.424)	-1.656 ^a (0.126)		-1.695 ^a (0.281)
Wholesale funding/assets at m-1	-7.463 (10.73)	-6.984 (11.05)	-7.021 (10.76)	-49.09 ^a (18.89)	-54.45 ^a (19.56)	-51.63 ^a (19.13)	-3.989 (2.860)	-5.957 ^c (3.124)	-3.755 (3.077)
CDS		-0.113 ^a (0.0236)	-0.114 ^a (0.0236)		-0.136 (0.129)	-0.0768 (0.128)		0.0688 ^a (0.00654)	-0.00205 (0.0136)
Constant	50.55 ^a (6.660)	53.57 ^a (4.813)	51.10 ^a (6.580)	41.10 ^a (5.607)	52.73 ^a (6.478)	43.13 ^a (6.451)	51.64 ^a (2.948)	37.08 ^a (2.367)	51.88 ^a (3.341)
Observations	475	475	475	242	242	242	543	543	543
R^2	0.093	0.117	0.118	0.238	0.207	0.239	0.577	0.548	0.577
Borrower FE	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 7: Transition Probabilities

	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum
Full Sample						
$Pr(X' > 0 X < 0)$	0.23	0.43	0.55	0.60	0.81	1.00
$Pr(X' < 0 X > 0)$	0.04	0.16	0.32	0.32	0.42	0.65
Period 1: Pre-crisis						
$Pr(X' > 0 X < 0)$	0.27	0.31	0.56	0.59	0.83	1.00
$Pr(X' < 0 X > 0)$	0.00	0.17	0.30	0.31	0.45	0.67
Period 2: Zero target						
$Pr(X' > 0 X < 0)$	0.18	0.43	0.55	0.61	0.82	1.00
$Pr(X' < 0 X > 0)$	0.05	0.13	0.36	0.33	0.47	0.77
Period 3: Crisis						
$Pr(X' > 0 X < 0)$	0.28	0.50	0.69	0.66	0.85	0.95
$Pr(X' < 0 X > 0)$	0.00	0.33	0.45	0.43	0.66	0.77

Notes: $Pr(X' > 0|X < 0)$ denotes the probability an FI is a lender today conditional on that FI being a borrower the last time they were in the overnight market. $Pr(X' < 0|X > 0)$ denotes the probability of an FI being a borrower today conditional on that FI being a lender the last time they were in the overnight market.

5 Economic Significance of Results

Given the results from the regressions above, we next quantify the size of these effects. First, consider a one-standard deviation decrease in the average borrower's distance-to-default, which implies an increase in borrower riskiness. If we use the estimated coefficient in column (5) of Table 6 (1.376) – for the pre-crisis period – this leads to a 2.8% decrease in bargaining power. By construction, there is a linear relationship between the bargaining power measure λ and the interest rate y ; specifically, a movement from $\lambda = 0$ to $\lambda = 1$ corresponds to the 50 basis point movement from the bank rate b to the deposit rate d . Hence, each percentage point decrease in bargaining power for the borrower corresponds to a *half basis point increase* in the implied interest rate. Therefore, the 2.8% decrease in bargaining power here corresponds to a 1.4 basis point increase in the interest rate faced by the borrowers.

In contrast, during the crisis period, we find that the same decrease in distance-to-default is associated with an increase in bargaining power of 3.5% (using the point estimate 1.695). This corresponds to a 1.73 basis point decrease in the interest rate faced by borrowers. Evaluated at the average overnight loan size of \$186 million, this implies that lending banks reduced interest

payments for risky borrowers during the crisis period by an amount of \$89 $(=(0.00173/360)*\$186$ mill). This is a small number. Similarly, calculations can be done with the other risk measures used in the bargaining regressions.

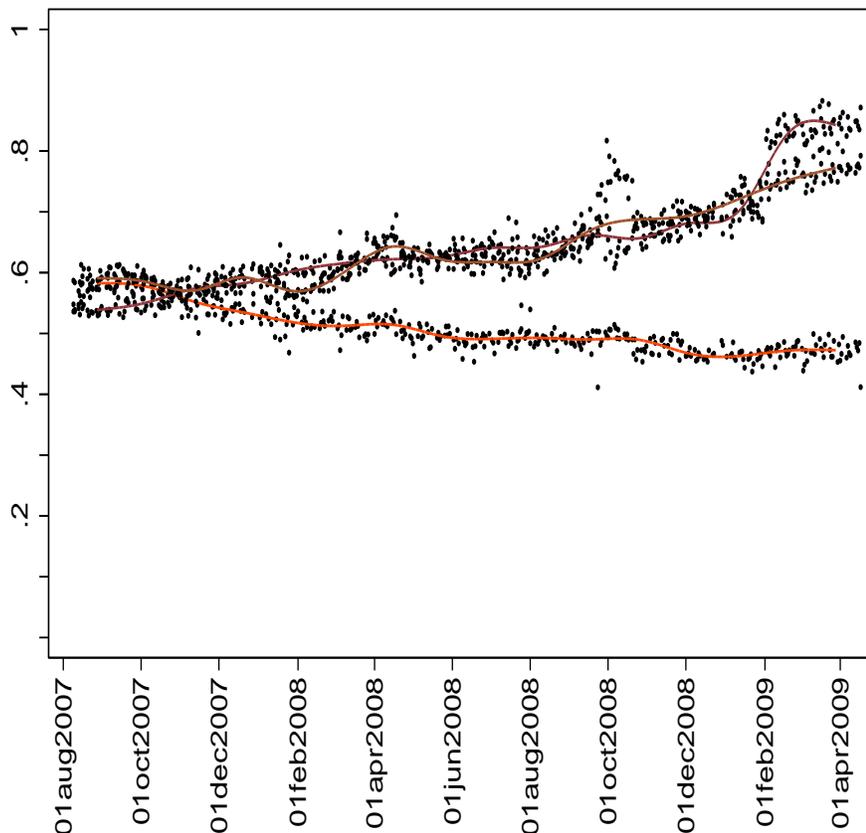


Figure 9: Actual versus counterfactual bargaining power for crisis-period loans

Top line: counterfactual bargaining weights (λ) using second-period regression coefficients; Middle line: counterfactual bargaining weights (λ) using first-period regression coefficients; Bottom line: actual bargaining weights (λ) using third-period regression coefficients.

More interesting than looking at the coefficients in the third period, we perform a counterfactual exercise in which we use the second-period (pre-crisis) regression coefficients, coupled with the observed loans in the third period, to predict what bargaining power *would have been* in the third pe-

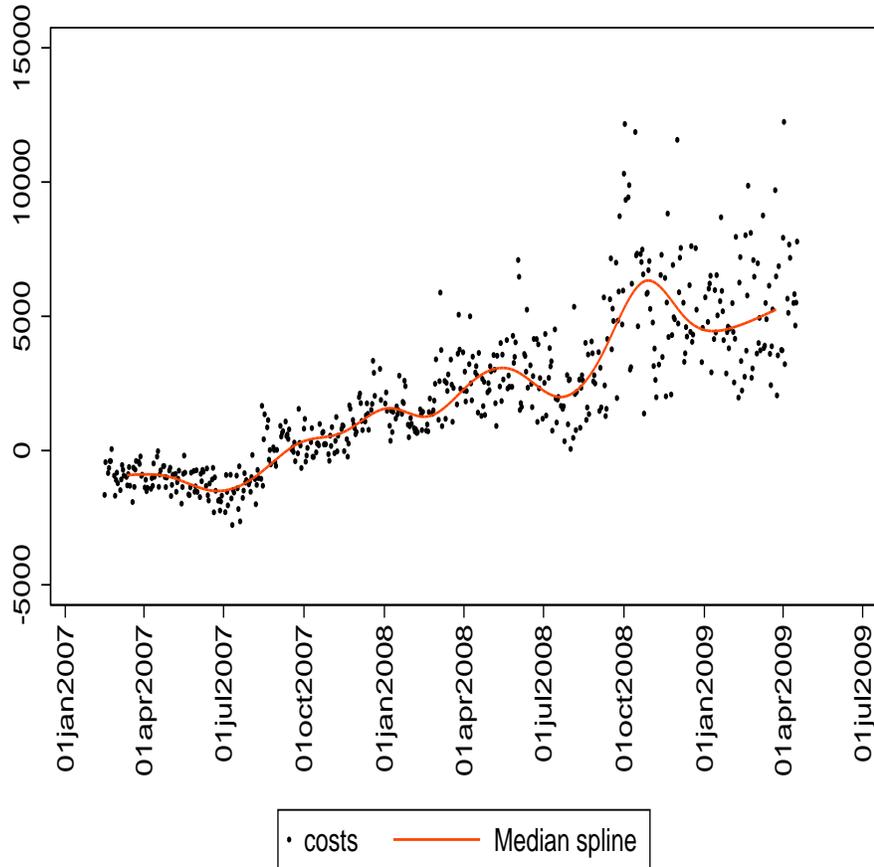


Figure 10: Costs of time-shift in bargaining power

This is a graph of the difference in the second-period counterfactual bargaining power and the actual bargaining power multiplied by the average loan size on each day and the one-day interest cost, i.e. $50\text{bps}/360$.

riod, without the shift in bargaining power towards riskier borrowers in the third period regressions. These counterfactual bargaining power measures are presented in Figure 9. The top line in this graph presents the counterfactual values of λ . This line trends upward over time, indicating that, in the absence of the negative coefficient between distance-to-default in the regressions, bargaining power would have shifted substantially to lenders between August 2007 and February 2009.

For comparison, the actual bargaining weights for the crisis-period loans, computed using the

third-period regression coefficients (including the negative coefficient on distance-to-default), are also presented in the graph. The divergence between the actual and counterfactual results is sizable: the actual bargaining weights steadily become more favorable to the borrowers, as the crisis proceeds.

To put this in monetary terms, we plot, in Figure 10, the “costs” of this crisis-time shift in bargaining power, in terms of the difference in interest payments which borrowers would have had to pay if their bargaining power followed the counterfactual path during the crisis, as compared to the actual path. Corresponding to the results in Figure 9, we find that these costs increase steadily over the crisis period. A cost of \$5,000 represents 31% of the average cost of an overnight loan at the sample average target rate of 3.16%. Measured this way, these costs of bargaining power shifting towards riskier borrowers in the crisis period are substantial.

6 Conclusion

In this paper we examine efficiency and bargaining power in the Canadian interbank loan market. This market, however, is complicated. The players are engaged in an imperfect competition game in which their actions are restricted by trading conventions making it difficult to characterize the equilibrium of such a game, which is a prerequisite to any analysis of bargaining and efficiency. Instead of modeling the multilateral trading environment in detail, we instead impose a very general and classical equilibrium concept: that of the *core*. This simply imposes a type of *ex-post* no-arbitrage condition on the observed outcomes.

We study efficiency and bargaining power of financial institutions in the Large Value Transfer System in Canada. Our results indicate that while the interbank market in Canada is fairly efficient, there is a systemic inefficiency that is persistent through our sample. Importantly, the efficiency of the system deteriorates with the liquidity interventions of the central bank. This result is in line with the views put forth by Goodfriend and King (1988) on the efficiency of the interbank market.

While we find that bargaining power is about equal between lenders and borrowers throughout the sample, during the financial crisis there was a shift in bargaining power *favoring borrowers*. Regressions confirm that as counterparty risk increased during the financial crisis, the riskier borrower banks were able to obtain better rates. There are a number of possible explanations. One possibility

is that the short-term cost of lending to a risky bank at a discount to an interconnected bank might be far less than the cost of having to mark down assets linked to a failed institution. A second reason is that liquidity can be episodic in an OTC market and because of repeated interactions among players who know this, banks are willing to lend to riskier banks in order not to be exploited in the future.

In ongoing work, we plan to explore the extent to which the repeated and dynamic interactions among the banks underly this result.

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