ESSAYS ON THE CANADIAN MORTGAGE MARKET

by

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Abstract

In this thesis, I investigate economic and policy issues presented in the Canadian mortgage market. In Chapter 2, I describe the institutional details and recent macroprudential regulations targeting the mortgage market—especially the mortgage stress tests. In Chapter 3, co-authored with Jason Allen, we develop a framework for investigating dynamic competition in markets where price is negotiated between an individual customer and multiple firms repeatedly. Using contract-level data for the Canadian mortgage market, we provide evidence of an "invest-then-harvest" pricing pattern: lenders offer relatively low interest rates to attract new borrowers and poach rivals' existing customers, and then at renewal charge interest rates which can be higher than what may be available through other lenders in the marketplace. We build a dynamic model of price negotiation with search and switching frictions to capture key market features. We estimate the model and use it to investigate (i) the effects of dynamic competition on borrowers' and banks' payoffs, (ii) the implications of dynamic versus static settings for merger-studies, and (iii) the impacts from stress tests on mortgage renewals. In Chapter 4, co-authored with Robert Clark, we show that Canadian banks behaved strategically to limit the efficacy of the mortgage stress tests, which require borrower qualification based on the mode of 5-year rates posted by the Big 6 banks rather than negotiated transaction rates. The government aimed to cool credit markets, but since many mortgages are government-insured, Big 6 interests were not aligned. Using a difference-in-difference approach comparing changes in 5-year spreads with 3-year spreads, unaffected by the policy, we find benchmark qualifying rates were lowered to encourage continued borrowing, muting the impact of the tests on borrower qualification.

Co-Authorship

Chapter 3 of this thesis, "Dynamic Competition in Negotiated Price Markets",[1] is co-authored with Jason Allen of the Economic and Financial Research Department at the Bank of Canada.

Chapter 4 of this thesis, "The Strategic Response of Banks to Macroprudential Policies: Evidence from Mortgage Stress Tests in Canada", is co-authored with Robert Clark of the Department of Economics at the Queen's University.

[1] The views in this chapter are those of the authors and do not represent those of the Bank of Canada.

Dedication

To my parents, my wife Yiyang, and my kids, for all of your love and support

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Chapter 1

Introduction

In this thesis, I investigate some important economic and policy issues presented in the Canadian mortgage market. Chapter 2 introduces the institutional details and describes recent macroprudential policies targeting the mortgage market, setting the stage for analyses in the next two chapters. Chapter 3 studies the dynamic competition in negotiated price markets through the case of Canadian mortgage market. Chapter 4 investigates the Canadian banks' strategic responses to mortgage qualification rule changes.

In Canada, a typical mortgage amortizes in 25 years. However unlike in the US, lenders do not offer mortgage products fixing interest rates for the entire amortization period. The majority of borrowers choose mortgage contracts with interest rate fixed over a 5-year term, and hence are required to renew their outstanding balances every 5 years to obtain new interest rates. Lenders advertise sticker prices, posted mortgage rates, for their mortgages products. But borrowers rarely pay the posted rates. They can often visit a few banks in their local markets, and negotiate with branch managers to receive discounts. Many other markets share the same features, where the price is negotiated between an individual customer and multiple firms repeatedly. Examples include auto insurance (Honka (2014)), health insurance (Dafny (2010)), and many business-to-business transactions (Salz (2017) and Marshall (2019)). In general, price negotiation implies non-trivial search costs to obtain meaningful quotes. Repeated interactions create switching costs and the possibility of dynamic pricing. Search and switching costs allow the incumbent firm to charge a higher price without losing the customer. Anticipating this incumbency advantage, forward-looking firms compete more aggressively ex ante to invest in their customer base. This is known as the "invest-then-harvest" pricing strategy.

In Chapter 3, co-authored with Jason Allen, we develop a framework for investigating this type of dynamic competition in negotiated-price markets. We make two main contributions to the literature. First, since the past empirical literature on negotiated-price markets has been focused on a static setting with myopic consumers and firms, our framework allows us to understand the potential biases resulted from static models. Second, our work contributes to the literature that studies dynamic pricing strategies introduced by switching costs. Most of the research in this literature focuses on posted-price markets, e.g. cellular service (Kim (2006)), packaged foods (Dubé et al. (2009)), cable television (Shcherbakov (2016)), etc. The common assumption is that consumers face no search costs and all prices are observed by consumers and the econometrician. Our framework takes into account the high search costs in negotiated-price settings and the fact that researchers often only observe the final contract price.

Using contract level data for the Canadian mortgage market, we provide evidence of an “invest-then-harvest” pricing pattern: lenders offer relatively low interest rates to attract new borrowers and poach rivals’ existing customers, and then at renewal in some instances, charge interest rates which can be higher than what may be available through other lenders in the marketplace. We build a dynamic model of price negotiation with search and switching frictions to capture the key market features. We estimate the structural model and use it to conduct counterfactual experiments. We find that a static model overestimates the benefit of eliminating search and switching costs because it ignores the changes in lenders’ investment incentives and pricing dynamics. For the same reasons, static merger analyses also yields biased results. In our experiment that simulates the impact of recently implemented mortgage stress tests, which imposed tighter borrower qualification criteria, we find 12% of new borrowers in our sample would fail if they were subject to it at renewal. For these unqualified renewers, the stress test would substantially increase the home bank’s market power and lead to a 10% increase in interest costs.

In Chapter 4, co-authored with Robert Clark, we study the Canadian banks’ strategic responses to recent macroprudential policy changes. Since the financial crisis, macroprudential regulations targeting mortgage-market vulnerabilities have been widely adopted. Mortgage eligibility rules such as restrictions on loan-to-value ratio or debt-to-income ratio were used to cool credit markets. The success of these policies, however, depends crucially on the response of financial intermediaries. We provide evidence from Canada suggesting that banks may have behaved strategically to limit the effectiveness of recently adopted policies, the mortgage stress tests. These tests tighten the debt-to-income constraints, requiring borrowers to qualify based on the mode of 5-year rates posted by the Big 6 banks rather than the negotiated transaction rates. The government aimed to cool credit markets, but the Big 6 interests were not aligned. Because many mortgages are government-insured such that lenders do not bear default risks, banks have little incentive to curb credit expansion. We find evidence of rate manipulation using a difference-in-difference approach comparing changes in spreads for 5-year mortgages with spreads for 3-year mortgages, which are not affected by the policy. The benchmark qualifying rates were lowered to encourage continued borrowing, muting the impact of the tests on mortgage qualification. A back-of-the-envelope calculation suggests that 25% more insured mortgages and 12.4% more uninsured mortgages would have failed the stress tests had the qualifying rate not been manipulated. Our results suggest that, in order to achieve the preferred target, macroprudential policy makers need to carefully consider the strategic responses from the affected agents.

Chapter 2

Background on the Canadian Mortgage Market

2.1 Institutional Details

The Canadian mortgage market is dominated by a small number of large players, including six national banks (Bank of Montreal, Bank of Nova Scotia, Canadian Imperial Bank of Commerce, National Bank of Canada, Royal Bank of Canada, and Toronto-Dominion Bank), one regional cooperative network (Desjardins in Quebec), one provincially owned financial institution (ATB Financial in Alberta), two other banks operating primarily in specific provinces (Laurentian Bank of Canada in Quebec and HSBC Bank Canada in Ontario, Alberta, and British Columbia), and two mortgage finance companies operating nationally (MCAP and First National). Together these lenders originate more than 85% of residential mortgages in Canada. For brevity, we denote these major lenders as the "big 12".

Other lenders in the Canadian mortgage market include local credit unions and private lenders. In addition, independent mortgage brokers can serve as intermediaries between borrowers and lenders. Brokers intermediate about one-third of mortgages over the period that we are studying. Allen et al. (2014b) provide a detailed analysis of brokers in the Canadian market, and Robles-Garcia (2019) for the UK market. Non-broker mortgage applications are done at the branch level and not electronically. Broker transactions often happen over the phone. Banks compete with rival banks in prices, but branches of the same bank do not compete against each other.

In Canada, most mortgage contracts have 25-year amortization periods, but have terms of between one and ten years, during which time the interest rate is either fixed or variable. Posted mortgage rates are set weekly and nationally. Lenders post their mortgage rates across different maturities, and these are common across all local markets. Borrowers, however, rarely pay the standard posted rates.[1] Normally, borrowers visit a few banks in a local market, and negotiate with branch managers to receive discounts off the posted rate.[2]

When the mortgage terms mature, borrowers need to renew their outstanding balances and renegotiate for new interest rates. Banks impose significant penalties for refinancing before the end of the term. Hence, refinancing within the term is

[1]From 2014 to 2017, more than 99% of borrowers pay less than the posted rates. This is much lower than in Allen et al. (2019). One of the reasons is that lenders now advertise two sets of posted rates – their standard posted rates used to calculate prepayment fees and discourage early refinancing, and 'specials'. The 'standard' posted rate represents a price ceiling since it is illegal to charge interest rates higher than one's posted rates. Specials tend to be targeted at first-time home-buyers and switchers.

[2]The average discount received by borrowers financing 5-year fixed-rate mortgages is about 220 basis points as of January 2020. Borrowers can also use mortgage brokers to gather quotes on their behalf. Normally, brokers provide free services to borrowers. Instead, they are compensated by lenders originating the mortgage with commissions, a certain percentage of the loans depending on maturity.

uncommon in Canada.[3] The most popular mortgage product is the 5-years fixed-rate mortgage (FRM).[4]

Mortgage markets in many other countries (e.g. Netherlands, Switzerland, UK) are similar: borrowers periodically renew short-term FRM over a much longer amortization period.[5] This rollover feature introduces a number of potential risks for borrowers. First, is renewal risk. A borrower's life situation might have drastically changed in five years, and banks might simply not lend to a renewer. See, for example, DeFusco and Mondragon (2019). Second, is interest rate risk. Households are exposed, and aware that they might face a very different rate environment at renewal.

With respect to renewal risk, this is largely mitigated by mortgage default insurance. In Canada, it is required by law to insure high-ratio mortgages, defined as mortgages with loan-to-value (LTV) ratios greater than 80% at origination. The insurance protects lenders in the case of borrower default, and covers the life of the mortgage. Mortgage insurance is provided by the Canada Mortgage and Housing

[3] This is unlike in the US. It is mostly because of the relative term length of the mortgage contract (5 years versus 30), which makes the benefits from refinancing, that might come from lower interest rates relative to the large penalties imposed, less attractive compared to simply waiting to renewal. Furthermore, refinancing in the US often occurs when borrowers move. In Canada borrowers can port their mortgage, i.e. their mortgage can be transferred to the new home.

[4] According to the *Financial System Review* published by the Bank of Canada in June 2018, 5-year fixed-rate contracts accounted for around 45% of the outstanding mortgages as of May 31, 2018. A borrower with a 5-year fixed-rate mortgage needs to renew the outstanding balance at the end of the term and negotiate for a new interest rate. Unlike in the US, the share of mortgages that fix interest rates for more than 5 years is very small: around 4% as estimated by the Canadian Association of Accredited Mortgage Professionals in 2010.

[5] In the UK most mortgages begin with a relatively low fixed rate for a period of 2-5 years, after which the rate resets to a much higher floating rate, giving borrowers incentive to refinance.

Corporation (CMHC), a federal Crown corporation, and two private entities: Genworth Financial and Canada Guaranty. The mortgage insurance premiums, 2.8%-4.0% of the loan amount depending on the LTV ratio, are always passed on to borrowers and rolled into the loan. For insured mortgages, banks must renew the remaining balances at maturity even in the case where the mortgages go underwater. Low-ratio mortgages (LTV below 80% at origination) have substantial equity, and renew risk is minimal, especially since Canada has experienced positive house price growth since the early 2000s.[6]

Mortgage lenders in Canada rely on a number of funding sources. According to the Residential Mortgage Industry Report published by CMHC in 2019, retail deposits are the largest source of funding, accounting for more than 60% of the mortgage funding market. Retail deposits tend to be insured by the Canada Deposit Insurance Corporation and are therefore a stable source of funding. Lenders have access to the mortgage securitization programs offered by CMHC to fund their mortgage origination. The majority of insured mortgages are securitized and the collection of securitized mortgages is often held on financial institutions' balance sheet as high-quality liquid assets to regulatory requirements. Overall, the National Housing Act Mortgage-Backed Securities (NHA MBS) make up about 30% of the mortgage market. In Canada, only about one per cent of mortgages are funded through private-label mortgage securitization. Lenders also use covered bonds as a stable and low-cost funding tool. There are tight limits on the amount of covered

[6] Borrowers with more than 20% down payment have the option to buy transnational mortgage insurance in exchange for better interest rate offers. Lenders can also purchase portfolio insurance for a pool of low-ratio mortgages in order to use mortgage securitization programs.

bond a lender can issue; the regulatory cap is four per cent of their total assets. Covered bonds are gaining market share in recent years, reaching around 10% of the mortgage funding in 2019. For more details on mortgage funding and mortgage securitization programs in Canada, see Crawford et al. (2013), Mordel and Stephens (2015), and Ahnert (2018).

2.2 Regulatory Framework and Macroprudential Regulations in Canada

Federal statutes require lenders to purchase mortgage insurance for borrowers obtaining high-ratio mortgages.[7] Lenders' loss is fully covered by the insurers in the case of borrower default. In the case that insurers fail to cover lenders' claim, the Canadian government guarantees 100% of the mortgage insurance obligations of CMHC, and 90% for the private insurers. Therefore, the government sets out eligibility rules for insured mortgages and adjusts them over time to support homeownership access while controlling for potential losses from providing the guarantee. These mortgage insurance eligibility rules are important macroprudential policy tools that the government uses to influence the housing and credit markets.

Low-ratio mortgages (LTV $\leq$ 80%) are normally not subject to mortgage insurance eligibility rules. However, those originated by federally regulated lenders are subject to mortgage underwriting guidelines B-20, which are established by the Office of the Superintendent of Financial Institutions (OSFI).[8] Federally regulated

[7] See section 418 and section 551 of *Bank Act*.

[8] All banks, cooperative credit associations, most trust and mortgage loan companies, and life insurance companies are federally regulated. Mortgage finance companies (MFC), mortgage investment corporations (MIC), private mortgage lenders, and provincially regulated credit unions are not directly subject to Guideline B-20.

financial institutions (FRFIs) together originate about 80% of mortgages.

Prior to the financial crisis, the government had been apply macroprudential policy tools in a pro-cyclical way to stimulate housing and credit growth. Macroprudential regulations were loosened to support access to insured mortgages: e.g. removal of regional house-price caps, less restrictions on sources of down payment, increase in LTV limit to allow zero down payment, extension of maximum mortgage amortization period from 25 to 40 years, etc.

Since 2008, however, the government has shifted its objective to contain the surging imbalances in housing and mortgage markets. Several rounds of macroprudential policy changes were introduced by the Department of Finance or OSFI. Some of regulations are targeted at household balance sheet, for example, restrictions on LTV ratio or deb-to-income (DTI) ratio. Other regulations include limit on house prices, reduction in maximum amortization period, requirement on minimum credit score, requirement on minimum documentation standard for property value assessment and income verification, etc. A partial list of policy changes is presented below:[9]

(i) In 2008, the Department of Finance tightened mortgage insurance eligibility rules to lower maximum LTV from 100% to 95%, shorten maximum amortization period from 40 to 35 years, set maximum total debt-servicing (TDS) ratio to 45%, set minimum credit score to 620, set minimum documentation standard, and exclude high-ratio mortgages starting with interest-only payments or home equity lines of credit (HELOCs).

[9] I abstract from policy changes that influence mortgage market activities indirectly, e.g. changes in mortgage securitization programs, changes in capital requirements for mortgage insurers, etc.

(ii) In 2010, the Department of Finance changed the insurance eligibility rules to mandate borrower qualification using qualifying rates for insured mortgages with fixed interest rates of less than 5 years,[10] lower maximum LTV from 95% to 90% for mortgage refinances, lower maximum LTV from 95% to 80% for rental properties,

(iii) In 2011 and 2012, the Department of Finance further tightened the rules to shorten maximum amortization period from 35 to 25 years, lower maximum LTV from 90% to 80% for mortgage refinances, withdraw low-ratio mortgage insurance provided to non-amortizing HELOCs, withdraw high-ratio insurance extended to houses with price above a million, set maximum gross debt-servicing (GDS) ratio at 39%, and reduce the maximum TDS ratio from 45% to 44%.

(iv) In 2012, OSFI released the Residential Mortgage Underwriting Practices and Procedures Guideline B-20, which expected FRFIs to qualify *uninsured* mortgages with fixed interest rates of less than 5 years using qualifying rates rather than negotiated transaction rates.

(v) In 2015 and 2016, the Department of Finance implemented new changes to insurance eligibility rules to increase the minimum down payment requirement for houses priced above $500,000, set tighter criteria for low-ratio mortgage insurance, and qualify all insured mortgages using qualifying rates.

[10] These are either fixed-rate mortgages with loan term less than 5 years or variable-rate mortgages regardless of the term.

(vi) In 2017, OSFI proposed changes to Guideline B-20, which requires FRFIs to qualify all *uninsured* mortgages using qualifying rates. This change came into effect in 2018.

Most of the policy changes listed above were strictly implemented. However, regulations requiring borrower qualification based on qualifying rate, know as *mortgage stress tests*, gave banks some leeway. The qualifying rate is determined based on the mode of the Big 6 banks' 5-year posted rates, and hence is normally much higher than negotiated transaction rates. The stress tests ensure that, other things equal, at the time of mortgage renewal borrowers would be able to continue satisfying the GDS and TDS constraints and servicing their mortgage loans even if interest rates were to rise to the qualifying rate level.

By setting its own posted rate, each individual bank among the Big 6 can indirectly control the stringency of the stress tests. The Big 6 has the incentive to adjust the qualifying rate for the purpose of profit maximization. However, their interests might not be aligned with the government's objective. Chapter 4 investigates how the Big 6 set qualifying rates to influence the tests.

Chapter 3

Dynamic Competition in Negotiated Price Markets

3.1 Introduction

This chapter develops a framework for investigating dynamic competition in markets where prices are negotiated between an individual customer and multiple firms repeatedly. Examples include mortgage markets (Woodward and Hall (2012) and Allen et al. (2019)), auto insurance markets (Honka (2014)), health insurance markets (Dafny (2010)), and many business-to-business transactions (Salz (2017) and Marshall (2019)). Customers in these markets normally face nontrivial costs of searching for price quotes and switching providers.

Search frictions are especially relevant in negotiated-price markets. Unlike in posted prices markets, where product comparison websites might be available, each price quote entails costly search and negotiation. In addition, repeated interactions over time induce switching costs.[1] Both search and switching costs lead to a form of lock-in that places the incumbent firm in a stronger bargaining position than rival firms and thereby increases its market power. The additional rents that accrue to an incumbent firm, however, mean that all firms compete more aggressively ex ante to build their customer base. In the presence of switching costs, we expect to observe dynamic pricing patterns: firms using relatively low prices to attract new customers and poach those of their rivals, and then charging higher prices once these customers are locked-in. In spite of the fact that firms in negotiated-price markets essentially solve dynamic optimization problems to trade off between current profits and future incumbency advantages, we are unaware of any quantitative study taking this salient feature into account.

In this chapter, we focus on one negotiated-price market, the Canadian mortgage market. In Canada, a typical newly originated mortgage amortizes in 25 years. Lenders, however, do not offer long-term contracts. The majority of home buyers take out 5-year fixed-rate mortgages (FRM). Hence, every five years borrowers are forced to renew their mortgage with either the current provider or a rival lender; a new interest rate must be negotiated for the outstanding balance. We take advantage of this deterministic timing for renegotiation to gain insight into the dynamic pricing game played by lenders.

Given our emphasis on dynamic pricing, we require information on mortgage contracts both at origination and at renewal. Importantly, we need to observe the

[1] A switching cost is incurred every time a customer switches providers. Switching costs may come from transaction costs related to switching providers, brand loyalty, or psychological cost of ending a current relationship, etc. See Klemperer (1995) for a detailed discussion.

identity of borrowers' current lenders and previous providers and hence borrowers' switching activities. We therefore use anonymized credit bureau data. TransUnion, a national credit bureau, provides the Bank of Canada monthly updates on the credit portfolios of the population of Canadian households, including contract-level information on mortgages. Starting in 2012, we observe a borrower's mortgage payment history and use it, along with balance changes, to back out the contract rate. Additionally, we observe borrower characteristics (age, credit score, location), contract information (original loan size, outstanding balance, funding date), and crucially the lender's identity and the borrower's switching behavior. Finally, for a subset of borrowers, we are able to match the credit bureau data to administrative data, providing us with additional borrower and contract information.

Our descriptive analysis provides preliminary evidence of "invest-then-harvest" pricing behavior: borrowers who renew their mortgage with their incumbent bank on average pay interest rates 6.1 basis points (bps) higher than new borrowers, and borrowers who switch banks at renewal on average pay 10.2 bps lower than those who stay. Consider an average newly originated mortgage of $264,000 that amortizes in 25 years. The differences in rates imply differences in total interest costs over five years of $746 to $1,243. In spite of these potential savings, only 12.1% of renewers switch mortgage providers.

In order to rationalize the observed pricing pattern, we build a dynamic model of price negotiation with search and switching costs. We follow Allen et al. (2019) but extend their model in an important way. Specifically, we incorporate and emphasize the intertemporal trade-off lenders face when pricing mortgage contracts. This trade-off influences the interpretation of equilibrium outcomes and has meaningful policy implications. For example, in a dynamic framework switching frictions need not necessary hurt consumers. Forward-looking lenders compete more aggressively for borrowers and this competition might result in lower prices. Our focus on pricing dynamics also highlights the importance of treating new and repeated customers separately in policy evaluations, because lenders price these two types of borrowers asymmetrically.

We model the mortgage financing process over the entire amortization period as a finite period game. The first period is mortgage origination, and the subsequent periods are renewals. The game ends when the mortgage is fully paid. Each period, the borrower (new or renewer) is attached to a home bank.[2] The home bank moves first to offer the borrower a free initial quote. Depending on the realization of a per-bank search cost, and the expected gain from search, the borrower either accepts the home-bank offer or chooses how many quotes to gather. If the borrower decides to search, she obtains quotes from an endogenously chosen set of lenders, and uses the best offer in hand to negotiate for even better quotes. Lenders face heterogeneous realizations of lending costs. They are willing to bid lower than the lending cost as long as the quotes generate positive expected profits over the life of the mortgage. Importantly, lenders are forward-looking and understand the future value of being a home bank, which includes (1) the first-mover advantage of making an initial offer that might retain borrowers drawing high search costs, (2) the opportunity of making

[2]The home bank for a new borrower is one with a pre-existing relationship, e.g. credit card. For a renewer, the home bank is the previous period mortgage provider.

additional offers given that borrowers always include their home bank in their choice set, and (3) the switching costs that could prevent borrowers from switching even if they receive slightly better quotes from rival lenders.

Our model describes the data generating process in a tractable way. The model primitives are (1) the borrowers' search cost distribution and switching cost, and (2) the banks' lending cost distribution and discount factor. We present an identification argument based on a dataset consisting of borrowers' interest-cost distribution and switching activity. The crucial assumption required is that there exists some observable(s) influencing borrowers' switching costs, but not the other model primitives.[3] In our empirical analysis, we estimate a parametric model using a cross-sectional sample of new borrowers and renewers to make use of observed heterogeneity across borrowers.

Overall, we find that banks' lending costs for the same borrower are not very dispersed. Borrowers, on the other hand, have nontrivial search and switching costs. On average they face a per-bank search cost of \$486 (that is 1.8% of the average interest cost) and obtain only 2.5 quotes, one of which is free from the home bank. For an average new borrower, the cost of switching away from a pre-mortgage relationship is \$115 (per \$100k loan). The number is tripled for renewers; it is much more costly to switch away from a mortgage relationship than a relationship, for example, based on a credit card.

We use the model to conduct counterfactual analyses to investigate (1) the effects

[3]For instance, the qualifying rate used in mortgage stress testing exogenously shifts borrowers' switching costs at renewal, and satisfies the exclusion restriction assumption. We discuss stress testing in detail in section 3.7.3. See also Clark and Li (2019).

of search and switching frictions on borrowers' and banks' payoffs, (2) the implications of dynamic versus static settings for merger analysis, and (3) the impacts of recently adopted mortgage stress testing in Canada. The first two experiments highlight the importance of understanding lenders' dynamic pricing strategies. The static model overestimates the benefit of eliminating search and switching costs because it ignores changes in lenders' investment incentives and pricing dynamics. For the same reasons static merger simulations overestimate merger impacts.[4] The last experiment, which exogenously increases switching costs, suggests that about 12% of new borrowers in our sample would fail the stress test if they were subject to it at renewal. For these unqualified borrowers, the stress test would substantially increase the home bank's market power and lead to a 10% increase in interest costs.

There is a large empirical literature investigating search frictions in markets where firms post prices. See for example, Sorensen (2001) for prescription drugs, Hortaçsu and Syverson (2004) for mutual funds, and Hong and Shum (2006) for textbooks. A typical assumption is that firms have common costs in servicing every consumer. In negotiated-price market, however, the final price that a customer pays is individualized to reflect the heterogeneity in firm-specific servicing costs, which might be unobserved to researchers. The main challenge is therefore to disentangle the distribution of both servicing costs and search costs from the observed negotiated-price distribution.

[4]This is consistent with MacKay and Remer (2019), who consider a hypothetical merger in a posted-price (gasoline) market, and find that a static model overestimates the post-merger price compared to a dynamic model that takes into account consumer inertia and firms' investment incentive.

There is also a large theoretical and empirical literature that focuses on switching costs in posted-price markets. See Klemperer (1995) and Farrell and Klemperer (2007) for an overview.[5]Recent empirical studies include Shum (2004) for the breakfast-cereal market, Kim (2006) for cellular service, Dubé et al. (2009) for packaged foods, Shcherbakov (2016) for cable television, Handel (2013) for health insurance, Fleitasl (2016) for drug insurance, and Illanes (2017) for pension plans. In banking markets there is also extensive interest in switching costs. See for example Ausubel (1991) for credit cards, Ho (2015) for deposits, Kim et al. (2003) for bank loans, and Thiel (2018) for the Dutch mortgage market.

From the above list, Dubé et al. (2009) and Shcherbakov (2016) investigate switching costs in dynamic frameworks. The authors find that switching costs can lead to lower equilibrium prices. Consistent with their findings, in a counterfactual experiment, we show that new borrowers' interest costs are lower with than without switching costs. Therefore, policies aimed at promoting competition through reducing switching costs may not be effective. These papers, however, ignore search frictions and assume that consumers have perfect information about the prices available in the market. This assumption is reasonable in posted-price markets but does not fit into a negotiated-price market setting.

In our negotiated-price setting, we only observe the final contract price rather than all the quotes obtained by borrowers. Therefore, we need to explicitly model

[5]Theory mainly focuses on the effects of switching costs where forward-looking firms compete repeatedly, and provides conditions under which switching costs are pro- or anti-competitive (c.f. Von Weizsäcker (1984), Klemperer (1987), Farrell and Shapiro (1988), Beggs and Klemperer (1992), Padilla (1995), Chen (1997), Somaini and Einav (2013), Fabra and García (2015), and Pearcy (2016).

how the observed price distributions are generated and how they are affected by search and switching frictions. Our approach is to approximate the price negotiation process as an English procurement auction, where lenders gradually lower their quotes to bid for a borrower. This setting captures, in a tractable way, the important feature that borrowers use the best offer in hand to extract better quotes, and lenders are willing to accept profitable counteroffers. The auction setting provides a clear interpretation of the final price, which is associated with the second order statistic of lenders' reservation values. Other studies applying auction-like models to approximate price negotiation include Woodward and Hall (2012), Rosenbaum (2013), Salz (2017), Beckert et al. (2018), Allen et al. (2019), Slattery (2019), and Cuesta and Sepulveda (2019).

In our model, firms' pricing strategies are not as complicated as in posted-price markets. When a firm posts a non-negotiable price, it applies to all potential consumers. Therefore, firms' pricing strategies depend crucially on their market shares: high-market-share firms have more incentive to raise prices and harvest consumers, while low-market-share firms tend to compete aggressively to invest in their customer base. Forward-looking firms take into account the effect of current prices on consumers' choices, future market shares, and future profits. They solve dynamic optimization problems under rational beliefs about the market share transition. In negotiated-price markets, prices are individualized. Firms' pricing strategies for different borrowers are independent, and hence are not constrained by their market shares.

There is now a growing literature that investigates both search and switching frictions in a unified framework. Wilson (2012), for example, points out that models taking into account only one type of market friction can generate biased estimates when both frictions exist. Honka (2014) quantifies search and switching costs in the US auto insurance markets using information on consumers' consideration sets, purchase prices, and switching behavior. Both Wilson (2012) and Honka (2014) assume a static framework, where firms' pricing do not take into account the future value of locked-in customers. Braido and Ledo (2018) build a parsimonious model of dynamic pricing competition in the Brazilian auto insurance brokerage market to rationalize the co-existence of zero and positive fees. Insurance brokers do not observe if consumers search for quotes, therefore, even though prices are individualized, the brokers play a mixed strategy in equilibrium to balance the trade-off between a low fee to strike a deal and a high fee to exploit the potentially locked-in customer. This does not fit into the setting of negotiated-price markets, where the key feature is that customers use current best quotes to negotiate for better offers.

This chapter is organized as follows. Section 3.2 introduces institutional details and the data. Section 3.3 describes the model primitives and and characterize the equilibrium. Section 3.4 discusses non-parametric identification of the model. Section 3.5 specifies our empirical framework. Section 3.6 presents the estimation results. Section 3.7 presents our counterfactual experiments. Section 3.8 concludes.

3.2 Institutional Details and Data

3.2.1 Institutional Details

In Canada, a typical newly originated mortgage amortizes in 25 years. The loan term, however, is much shorter, between one and ten years during which time the interest rate is either fixed or variable. Every week, lenders post their mortgage rates across different maturities, and these are common across all local markets. Website aggregators then advertise these rates along with a host of other lender rates and might even provide advice. Nonetheless, less than 1% of borrowers pay the standard posted rate. Normally, borrowers visit a few banks in a local market, and negotiate with branch managers to receive discounts off the posted rate. Banks compete with rival banks in prices, but branches of the same bank do not compete against each other.

The majority of home buyers take out 5-year FRMs. Mortgage markets in many other countries (e.g. Netherlands, Switzerland, UK) are similar: borrowers periodically renew short-term FRM over a much longer amortization period. This feature makes studying banks' pricing strategies substantially easier than the U.S. market where borrowers sign long-term contracts and have an option to refinance where it is advantageous to do so. Chen et al. (2018), for example, document strong countercyclical mortgage refinancing activity associated with equity extraction. The refinancing decision is therefore endogenous.[6] This substantially complicates the search

[6]Ambokar and Samaee (2020) are the first to attempt modeling mortgage-demand with endogenous refinancing. In order to do so, however, they have to abstract from supply-side dynamics and the original issuance of the mortgage.

and switch decision for borrowers as well as the pricing strategies for lenders. Mortgage renewal in Canada, however, is almost entirely exogenous and depends on the date of origination. We take advantage of the deterministic timing for repeated interactions to gain insight into the dynamic pricing strategies of lenders.[7] We leave for future work an extension of the model to allow endogenous refinancing, which is more appropriate for thinking about the U.S. mortgage market.

How do renewals work in Canada? A household will typically sign a 5-year FRM. Near the end (typically six months prior) of the term, the incumbent lender sends the borrower a notice by mail about the upcoming renewal and offers a rate.[8] If the borrower does not engage at this time, the lender sends a new letter at the three-month mark, potentially with a new rate. It is often at this three-month mark that the lender and borrower start to negotiate, and the borrower may search for better offers from rival banks. A clear advantage for the incumbent is that borrowers face non-trivial switching costs.[9] In addition, unlike in posted-price markets, it is costly for borrowers to obtain quotes from rival banks. The home bank enjoys a first-mover advantage by offering an initial quote that might prevent the borrower from searching.

[7] A further benefit of fixed renegotiation is that we can better interpret consumer inertia as either coming from search costs or switching costs and not from inattention (c.f. Andersen et al. (2017) and Agarwal et al. (2015).)

[8] Loan originator and loan servicer are the same in Canada. By law, federally regulated lenders must provide borrowers with renewal statements 21 days before the mortgage maturity dates. See Appendix A for an example of a renewal letter.

[9] The monetary costs of switching lenders include the appraisal fee to verify a property's value, an assignment fee to transfer the mortgage from the home bank to the new provider, and sometimes a discharge fee. as well as legal fees if the mortgage is a collateral-charge product. Psychological costs also seem to be relevant. According to the 2018 Mortgage Consumer Survey conducted by the Canada Mortgage and Housing Corporation, other than rates, the top reason for not switching is the value placed on a pre-existing relationship.

3.2.2 Data

Our main data set comes from TransUnion, one of two credit bureau companies operating in Canada, which collects information on credit products for the Canadian population. We focus on mortgages, but are also able to control for other debt such as auto loans, lines of credit, demand loans, credit cards, student loans, and utilities.[10] All major lenders report their borrowers' monthly payment records from January 2012 to July 2019. The dataset contains anonymized information on borrowers' characteristics: age, credit score, non-mortgage debt obligations, monthly payments, and physical address up to the forward sortation area (FSA).[11] We also observe mortgage contract information, including the lender's identity, loan amount, term, amortization, funding date, monthly payment, outstanding balance, and an indicator for mortgage insurance.[12] We use the monthly payment and changes in outstanding balance to calculate the interest rate and effective amortization. We use the interest rate pattern to identify the loan term whenever it is missing. We also calculate the interest costs over the loan term as our price measure. In addition, we use the lender's identity to identify switching behavior. We define the new borrowers' home

[10] TransUnion has monthly reports for over 35 million individuals. This is approximately 13 TB of data. To construct our dataset, we search the entirety of the population using PySpark for anyone with a mortgage. We capture their monthly mortgage payments and aggregates for other debt as well as information about age, home location and credit score. The raw sample is approximately 50 GB.

[11] The FSA is the first three digits of a postal code. The median population of an FSA is 18,000.

[12] We observe both the monthly required payment and the actual payment made. Borrowers are allowed to prepay a certain amount every month. Therefore, the actual payment might exceed what is required. Also, mortgage insurance is mandatory for mortgages with LTV ratios greater than 80%.

banks by the pre-mortgage relationships built on other credit products.[13]

In addition to monthly credit bureau data, we access a second anonymized contract-level administrative dataset, which offers information on mortgages provided by federally regulated lenders. We match individuals at the loan-account level. This dataset is similar to that used in Allen et al. (2019).[14] Although it lacks information on a borrower's previous lender, it allows us to complement the credit bureau data by including information on the borrower's income, broker usage, house value, loan-to-value ratio, and total debt-servicing ratio. We also supplement our data set with 2016 FSA-level demographic information such as population and median income level. Finally, we include the quarterly FSA-level house price index and housing transaction number generated by Teranet.

We obtain a cross-sectional sample of new borrowers and first-time renewers, who negotiated their interest rates within the period from January 2014 to December 2017. We then further restrict our sample to keep only insured mortgages that were negotiated individually (without a broker) and with 5-year fixed-rate terms.[15] We drop borrowers who have moved, taken out equity, or opened multiple mortgages. Finally, we only keep mortgages provided by four specific big banks that record the

[13] Some borrowers have multiple banking relationships prior to obtaining a mortgage. If the borrower chooses such a bank, we assume that the chosen bank is the borrower's home bank.

[14] Allen et al. (2019) focus on newly originated contracts only. Our study requires observing renewers' contract information, and crucially their previous lender and switching behaviors.

[15] The share of uninsured mortgages during our sample period is around two thirds. We do not model the choice of broker usage because we do not have the necessary information to interpret the interest rate obtained through the broker channel. For example, for each contract we need to observe (i) the broker's identity, (iii) the set of lenders searched by the broker, and (iii) the baseline interest rate and compensation scheme specified by each lender. The third point is important because brokers might not work for the best interest of the borrower and might choose high-commission products over low-interest ones. In addition to the data requirement, we also need to model the way in which lenders compete in the broker channel. We leave this for future work.

most accurate information.

We define a local market at the FSA level. More formally, we follow Allen et al. (2019) and assume borrowers can search for quotes from any of the big 12 lenders that has a branch located within 10 KM of the centroid of their FSAs. We treat the two mortgage finance companies as a single option, and assume it is available across all markets. Indeed, they have originated mortgages in more than 90% of FSAs.

3.2.3 Market Features

In this subsection, we present some descriptive evidence that motivates the development of our structural model. In Section 3.3, we build a model that captures and explains these salient market features. Table 3.1 presents the summary statistics of borrowers' characteristics and contract information. Table 3.2 reports the regression results that describe the correlations between negotiated contract rates and borrower characteristics. We present five key features that characterize the pricing pattern and shopping behavior in the Canadian mortgage market. Similar features are also shared by most negotiated-price markets.

Feature 1: Mortgage rates are determined via negotiation. Most lenders post a common interest rate for all potential borrowers and then offer individual-level discounts. Less than 1% of borrowers pay the posted price.

Table 3.1: Summary Statistics

	mean	sd	p25	p50	p75
	Panel A: New Borrowers				
Interest Rate	2.75	0.29	2.59	2.69	2.90
Outstanding amount	253.72	123.36	164.95	234.27	322.15
Origination amount	253.72	123.36	164.95	234.27	322.15
Credit score	754.01	50.48	721.00	757.00	792.00
Age	36.15	10.66	28.00	33.00	42.00
Bond rate	1.04	0.37	0.73	0.92	1.44
Amortization	24.08	1.86	22.36	24.95	25.00
No. of lenders	6.58	1.85	6.00	7.00	8.00
FSA income	77.34	22.24	61.76	73.10	89.73
FSA house price	380.33	162.62	262.11	336.36	479.55
FSA transaction no.	7557.42	15168.21	476.00	1200.00	3196.00
	Panel B: Renewers				
Interest Rate	2.81	0.36	2.60	2.70	2.99
Loyal renewal	2.82	0.36	2.60	2.74	2.99
Switch renewal	2.71	0.29	2.50	2.64	2.89
Outstanding amount	191.40	92.33	124.98	176.06	242.77
Origination amount	220.94	104.79	145.92	204.35	280.00
Credit score	781.20	76.59	734.00	794.00	842.00
Age	45.78	11.94	36.00	44.00	54.00
Bond rate	1.07	0.38	0.75	0.94	1.51
Amortization	21.19	5.24	17.39	20.29	24.96
No. of lenders	6.78	1.85	6.00	7.00	8.00
FSA income	77.74	22.59	61.63	73.52	90.68
FSA house price	396.73	189.39	263.90	342.91	489.43
FSA transaction no.	5895.41	13325.42	429.50	1029.00	2617.00

Note: The sample includes 16,711 mortgage contracts negotiated between 2014 and 2017: 8,131 are new borrowers, and 8,580 are renewers (including 1,037 switchers). Units for outstanding amount, origination amount, FSA income and house prices are $1,000; units for interest rate and bond rate are percentage points, and units for amortization and age are years. Outstanding amount refers to the current outstanding balance of the mortgage contract, while origination amount is the initial loan amount for a newly issued mortgage. Number of lenders is within 10km of the borrower's FSA centroid. FSA income is the median income level of the borrower's FSA recorded in the 2016 Census. FSA house price and FSA transaction number are, respectively, the average house price and the total number of housing transactions within the borrower's FSA in the quarter of origination/renewal and taken from Teranet.

Feature 2: Borrowers shop around for lower interest rates taking into account the cost of obtaining quotes and switching. Mortgage products offered by different lenders are fairly homogeneous. According to CMHC's Mortgage Consumer Survey in 2018, the top reason for a borrower to choose a specific lender is a better interest rate. Other than rates, borrowers value most convenience and trust in existing relationships.

Table 3.2: Regression Results

	Interest Rate (bps)	
Credit score	-0.0431***	(0.00385)
Outstanding amount	-0.0276***	(0.00218)
Bond rate	0.421***	(0.0117)
Amortization	0.247***	(0.0627)
FSA income	-0.0121	(0.0114)
Age	0.0733***	(0.0189)
House price (log)	-2.684***	(0.768)
Transaction no. (log)	-0.948***	(0.215)
No. of lenders	-0.777***	(0.154)
Loyal renewal	6.139***	(0.585)
Switch renewal	-4.026***	(0.830)
Observations	16,711	
R^2	0.395	

Note: This table presents results from an OLS regression of mortgage rates (in basis points) on observable transaction characteristics. We include year and region fixed effects, and lender fixed-effects. Units for outstanding amount and FSA income are $1,000, and units for interest rate and bond rate are basis points. Number of lenders is within 10km of the borrower's home. Region is defined as the first digit of the postal code. Robust standard errors are reported in parenthesis. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Feature 3: Most borrowers only search for quotes from a subset of lenders available in their local markets. Survey evidence from the Canadian Association of Accredited Mortgage Professionals in 2009 shows that about 95% of borrowers obtain no more than 4 quotes. The 2018 Mortgage Consumer Survey conducted by CMHC finds that borrowers on average contact 2.8 lenders. The average number of quotes reported in Allen et al. (2014b) was under 3. Table 3.1, however, suggests that the average number of available lenders in local markets is close to 7.[16]

Feature 4: Renewers rarely switch even though switchers tend to have better interest rates. Table 3.1 shows that only 12.1% of renewers switch banks. This is despite the fact that switchers, on average, receive a discount relative to non-switchers of 11 bps.

Feature 5: An "Invest-and-harvest" pricing pattern. Borrowers renewing with their home bank tend to pay higher interest rates than new borrowers. This can be seen from the summary statistics in Table 3.1, as well as the regression estimates in Table 3.2.

3.3 Model

Consider a borrower i searching for a mortgage contract with interest rate fixed for m years, and amortizing in $T \times m$ years. We model this as a T-period game. Each period can be further broken down into two stages: an initial quote stage where the borrower receives a quote from her home bank and decides to accept or search for more quotes, and a negotiation stage, where the borrower negotiates price with

[16] Honka (2014) finds that consumers in US auto insurance markets on average obtain only three quotes while the number of insurance companies is more than ten.

multiple lenders in her choice set if she rejects the home-bank offer. Since prices are individualized, we treat each borrower as an independent market. For brevity, we omit the borrower's index i, and add it back in the next section to emphasize borrower heterogeneity.

3.3.1 Preferences and Costs

Borrower Preferences. In each period $t = 1, 2, \cdots, T$, the borrower is attached to a home bank h^t. In $t = 1$, the home bank is the lender that had provided the borrower with some other product prior to the mortgage. In $t > 1$, the home bank is just the lender providing the mortgage in the previous period.

At the beginning of every period, the home bank moves first by offering the borrower a free initial quote p_0^t. The borrower can either accept p_0^t or reject the offer and search for more quotes by paying a per-bank search cost κ^t drawn from a distribution $H(\cdot)$. There are N^t lenders available in the borrower's local market. If the borrower rejects the home-bank offer, this initial offer cannot be recalled.[17] She will choose a subset of available lenders as her choice set $n^t \subseteq N^t$,[18] maximizing her expected net benefit from searching, in which the home bank is always included.

[17]This assumption simplifies home banks' problem of solving the optimal initial quote and is also reasonable in our setting. One might think that the borrower must be able to recall the offer specified in her renewal letter. However, in reality, banks often offer the highest that they can charge (the standard posted rates) in the renewal letters. See Appendix A for an example. These quotes are not worth recalling. In such case, borrowers can simply call their home banks asking for quotes better than the posted rates and the banks would propose new offers. Therefore, one should think of the home banks' "initial" quotes as these new offers rather than the posted rates in renewal letters. It is reasonable to assume that these offers cannot be recalled if the borrowers do not accept them and go through the paperwork.

[18]We assume symmetric lenders; n^t refers to both the choice set and number of lenders in this set.

The borrower then negotiates with all n^t lenders, and commits to take the best offer. Given the quotes, the borrower solves a discrete-choice problem and chooses a lender that maximizes her expected present value from financing a mortgage:

$$\max_{j \in n^t} v_j^t - p_j^t + \rho U_j^{t+1}, \tag{3.1}$$

where v_j^t is the borrower's valuation for a mortgage provided by lender j, p_j^t is the interest payment required by lender j, ρ denotes the borrower's discount factor, and U_j^{t+1} denotes the continuation value of being attached to lender j.

Since products are homogeneous, the borrower has no special preference for any lender other than a utility loss from switching:

$$v_j^t = \begin{cases} \bar{v}^t, & j = h^t \\ \bar{v}^t - \lambda^t, & \text{o/w.} \end{cases}$$

We assume $\bar{v}^t$ is finite but high enough that the borrower always demands a mortgage. There is no outside option.

Lending Costs. The lending cost measures the direct and indirect cost of providing a mortgage (i.e. funding costs, default and prepayment risks, overhead expenses, etc.), net of the expected future profits that might be derived from a borrower. In the negotiation stage, the lending cost for bank j is:

$$c_j^t = c^t + \omega_j^t.$$

We assume all lenders face a common funding cost, c^t, drawn from a distribution $F(\cdot)$. This common component captures lenders' consensus estimates regarding the borrower's profitability. For example, a part of it can be the cost of retail deposits or the borrower's prepayment risk. Randomness in the common cost absorbs heterogeneity across borrowers that is observable to lenders but not to the econometrician. We also allow each lender to have a different match value with the borrower, denoted as the idiosyncratic cost component ω_j^t, which is drawn *i.i.d.* from a mean-zero distribution $G(\cdot)$.

In the initial-quote stage, we assume that the lending cost from the home bank is just the common cost component, c^t. The motivation for this assumption is that borrowers only draw an idiosyncratic match value when they enter negotiations with a loan officer.[19]

3.3.2 Timing and Information

In each period t, we divide the price-generating process into two stages. In the initial quote stage, the home bank offers a free quote. The borrower can accept the offer (end of the game in period t), or search for more quotes. Given the number of available banks in the local market, N^t, the borrower decides the number of banks to be included in the choice set, n^t, and commits to take the best offer. At this point, the borrower has met with all lenders within the choice set and is ready to step into the negotiation stage. In this stage, the negotiation process is approximated as an English auction: the borrower obtains quotes from all lenders in the choice set and

[19]Individual loan officers have substantial discretion to offer discounts off the posted price. Larger discounts typically reduce the commission earned by loan officers; see KPMG (2008).

uses the best offer in hand to negotiate for even better quotes. This process goes on until the borrower obtains an offer that no other lender is willing to beat. The winning lender provides the highest expected utility, and becomes the borrower's home bank in the next period. The auction setting provides a clear interpretation of the final price, which is associated with the second order statistic of lenders' reservation values.

The borrower and lenders learn about borrower preferences and lending costs in sequence. In stage one the home bank, h^t, notices that the borrower is looking for a new mortgage ($t = 1$) or renewing her remaining balance ($t > 1$). The state variables commonly observed by both parties are the home-bank identity h^t, the number of locally available lenders N^t, the common cost realization $c^t \sim F(\cdot)$, and the switching cost λ^t. The search cost distribution $H(\cdot)$ and the idiosyncratic cost distribution $G(\cdot)$ are also common knowledge, but the search cost realization κ^t is the borrower's private information. For simplicity, assume N^t and λ^t do not vary over time. The commonly observed state vector in period t is just (h^t, N, c^t, λ). Given the state $(h^t, N, c^t, \lambda, \kappa^t)$ in the initial quote stage, the home bank chooses a price p_0^t, and the borrower decides n^t.

In the negotiation stage, each lender in the choice set draws an idiosyncratic cost shock ω_j^t *i.i.d.* from $G(\cdot)$. The distribution is commonly known, but the cost realization is private information. Denote the full state vector in period t as $s^t = (h^t, N, c^t, \lambda, \kappa^t, \boldsymbol{\omega}^t)$, where $\boldsymbol{\omega}^t$ is the vector of idiosyncratic cost draws. At this point, lender j chooses the quote to offer p_j^t, and the borrower determines the winner in the English auction (w^t).

Note that the only state variable determined by past actions is the home-bank identity:

$$h^{t+1} = \begin{cases} h^t, & n^t = 1, \\ w^t, & \text{o/w.} \end{cases}$$

The remaining state variables in the next period either stay the same (N, λ) or are determined by a new draw from a certain distribution $(c^{t+1}, \kappa^{t+1}, \boldsymbol{\omega}^{t+1})$.[20]

In what follows, we first characterize the equilibrium bidding strategies and equilibrium pricing functions in the negotiation stage conditional on the borrower's chosen choice set. We then solve the borrower's problem of choice-set formation and the home bank's problem of optimal initial-quote offering.

3.3.3 Negotiation Stage: English Auction

In each period t, conditional on n^t, we solve for the equilibrium pricing functions. If $n^t = 1$, the borrower is satisfied with her home bank's initial offer and does not enter into the negotiation stage. The equilibrium price is $p^{t*} = p_0^t$.

If $n^t \geq 2$, lenders compete in expected utility via an English auction. An English auction approximates negotiation by capturing two important features in the process: (1) borrowers use the best offer in hand to extract better quotes, and (2) lenders are

[20] The assumption of *i.i.d.* idiosyncratic cost draws greatly simplifies the model, and hence allows us to focus on the pricing dynamics induced by search and switching costs rather than the potentially minor asymmetry in cost structure. We discuss this in detail in subsection 3.3.3. Given the similarity in funding sources across the large Canadian banks, this assumption seems reasonable. In general, the symmetric cost assumption is applicable in markets where consumers obtain quotes from fairly comparable firms.

willing to lower their offers to win as long as they expect positive profits.

The weakly dominant bidding strategy is to bid one's reservation value (cost). Lenders drop out at the point where they are indifferent between winning and losing. Let the current best offer be $\tilde{b}^t$. Lender j stays in the auction and keeps bidding so long as the present value of winning at $\tilde{b}^t$ is greater than the present value of losing:

$$\begin{aligned}\tilde{b}^t - c_j^t + \sum_{\tau=t+1}^{T} \delta^{\tau-t} E[\Pi_j^\tau(h^\tau, \boldsymbol{\omega}^\tau, \kappa^\tau, N, \lambda) | h^{t+1} = j] \\ \geq \sum_{\tau=t+1}^{T} \delta^{\tau-t} E[\Pi_j^\tau(h^\tau, \boldsymbol{\omega}^\tau, \kappa^\tau, N, \lambda) | h^{t+1} \neq j],\end{aligned} \tag{3.2}$$

where δ is the lenders' discount factor, Π_j^τ is lender j's per-period profit function in period τ, and the expectation is taken with respect to the future shocks in $\boldsymbol{\omega}^\tau$ and κ^τ. Denote $W_j^{t+1} = \sum_{\tau=t+1}^{T} \delta^{\tau-t-1} E[\Pi_j^\tau(h^\tau, \boldsymbol{\omega}^\tau, \kappa^\tau, N, \lambda) | h^{t+1} = j]$ as lender j's continuation value of winning the auction, and $L_j^{t+1} = \sum_{\tau=t+1}^{T} \delta^{\tau-t-1} E[\Pi_j^\tau(h^\tau, \boldsymbol{\omega}^\tau, \kappa^\tau, N, \lambda) | h^{t+1} \neq j]$ its continuation value of losing. Since all lenders have a symmetric cost structure, the continuation values are the same across lenders.[21] We therefore drop the lender index j. Note that current actions do not affect the continuation values. While formulating bids, the lenders can simply treat them as constant.

The equilibrium bidding strategy for lender j specifies the price level at which it will drop out of the competition:

$$b_j^t(c^t, \omega_j^t) = c^t + \omega_j^t - \delta(W^{t+1} - L^{t+1}). \tag{3.3}$$

Lenders might bid lower than their costs because they take into account the future value of winning the contract. The net continuation value of winning $V^{t+1} \equiv W^{t+1} - L^{t+1}$ describes the future benefits of being a home bank in period $t+1$, and also represents the value of an attached borrower. V^{t+1} highlights the lenders' investment incentives: banks compete ex ante for a future incumbency advantage. Given that it depends on the home bank's profit and hence the borrower's search decision, we

[21] In the terminal period, the continuation values are 0. In each of the prior periods, a specific bank j's continuation value of winning is the same as the other lenders'. Whichever lender wins the current auction, it enters the next period as the home bank and plays the same game delineated in subsection 3.3.2. More importantly, conditional on the market structure N, the switching cost λ, and whether or not it is the home bank, a lender's expected profit only depends on the future realization of $\boldsymbol{\omega}$ and κ, which are drawn independently and repeatedly every period. Therefore, a lender's current bid would not affect the continuation values W^{t+1} and L^{t+1}. This greatly simplifies the equilibrium bidding strategies and the calculation of continuation values. To understand how asymmetric idiosyncratic cost distributions complicate the model, consider a case with two types of lenders, one of which is more likely to draw relatively low idiosyncratic costs. The continuation values now depend on the winning bank's identity (and hence the bidding strategies): L^{t+1} is higher if the winning bank is of high cost since it is more likely to poach the borrower in the next period. Therefore, while formulating the bidding strategies, lenders need to form beliefs about the winning probabilities of the other competitors', which need to be updated every time a lender drops out. We can no longer ensure that there exists a unique equilibrium. Nonetheless, if we have access to more information (e.g. choice set chosen, drop-out order, and drop-out prices), the model could be estimated using the two-step estimation method proposed by Bajari et al. (2007), assuming lenders play the same type of equilibrium for each borrower.

show exactly how it can be calculated after solving the home bank and the borrowers problems in the initial quote stage (see subsection 3.3.5).

Due to switching costs, the winner is determined by the ranking in expected utility rather than in bids. In particular, given the equilibrium bidding strategies and the switching cost λ, if bank j wins the auction, the equilibrium price p_j^{t*} should satisfy:

$$\bar{v}^t - \lambda \mathcal{I}_{j \neq h^t} - p_j^{t*} + \rho U_j^{t+1} = \max_{k \neq j} \{\bar{v}^t - \lambda \mathcal{I}_{k \neq h^t} - b_k^t + \rho U_k^{t+1}\}, \tag{3.4}$$

where $\mathcal{I}_{j \neq h^t}$ is an indicator function that equals 1 if j is not the home bank. The right hand side of equation (3.4) represents the highest expected utility/surplus that the rival banks can offer. Because lenders have symmetric cost structures, the continuation value of being attached to any bank U_j^{t+1} is the same. At the end, the highest surplus lender wins at a price just beating the second best option. Specifically, we can write the equilibrium price as a function of the state vector:

$$p^{t*}(s^t) = \begin{cases} c^t - \delta V^{t+1} + \omega_{(2)}^t + \lambda, & \omega_{h^t} - \lambda = \omega_{(1)}^t \\ c^t - \delta V^{t+1} + \omega_{(2)}^t, & \omega_{h^t} - \lambda \leq \omega_{(2)}^t \end{cases} \tag{3.5}$$

where ω_{h^t} is the home bank's idiosyncratic match value and $\omega_{(k)}^t$ denotes the k^{th} order statistic among $(\omega_{h^t} - \lambda, \omega_1, \omega_2, \cdots, \omega_{n^t-1})$.[22] Equation (3.5) describes the equilibrium price in cases where the home bank ranks 1^{st} and the 2^{nd} or lower place in terms of expected utility. This equation shows that lenders compete aggressively

[22] The equilibrium price depends on the search intensity through the number of idiosyncratic cost draws.

ex ante for the *ex post* rent, V^{t+1}. The home bank clearly enjoys an incumbency advantage originating from the switching cost, λ.

3.3.4 Initial Quote Stage

Given the home bank's offer p_0^t and the search cost realization κ^t, the borrower's trade off is between accepting p_0^t or paying $(n^t-1)\kappa^t$ to obtain the expected winning price $E[p^{t*}(s^t)|n^t]$, where the expectation is taken with respect to the idiosyncratic cost shocks drawn by the n^t lenders in the choice set.[23]

Given p_0^t and the equilibrium pricing function (3.5), we can calculate the expected equilibrium price conditional on $n^t = l$:

$$\begin{aligned} E[p^{t*}|n^t = l] &= Pr(\omega_{h^t} - \lambda \leq \omega_{-h^t}|n^t = l)E[c^t - \delta V^{t+1} + \omega_{(2)}^t + \lambda|n^t = l] \\ &\quad + Pr(\omega_{h^t} - \lambda > \omega_{-h^t}|n^t = l)E[c^t - \delta V^{t+1} + \omega_{(2)}^t|n^t = l] \\ &= c^t - \delta V^{t+1} + E[\omega_{(2)}^t|n^t = l] + Pr_{h^t}\lambda, \end{aligned}$$

where $Pr_{h^t} = Pr(\omega_{h^t} - \lambda \leq \omega_{-h^t}|n^t = l)$ is the probability that the home bank wins the auction and $\omega_{-h^t} = \min_{j\in n^t\setminus h^t}\{\omega_j^t\}$ is the minimum among the n^t-1 idiosyncratic cost shocks drawn by the rival banks in the choice set.

We can then write $\bar{\kappa}_l^t$ as the total expected gain from searching l lenders versus

[23]We assume that the borrower qualifies for a mortgage at every lender. Therefore, the borrower searches only for a lower price rather than to qualify. In the empirical analysis, we restrict our attention to only mortgages insured by the government. It is reasonable to assume that borrowers never get rejected, since the government bears all the default risk. See Agarwal et al. (2017) for a model that takes into account the interaction between searching and screening in the presence of asymmetric information. Borrowers' mortgage applications might get rejected, and they are forced to search more for approval.

accepting the initial offer, taking into account the expected utility loss from switching.

$$\bar{\kappa}_l^t = \begin{cases} 0, & l = 1, \\ p_t^0 - \lambda - (c^t - \delta V^{t+1} + E[\omega_{(2)}^t | n^t = l]), & l = 2, 3, \cdots, N. \end{cases} \tag{3.6}$$

The expected marginal benefit from searching l instead of $l-1$ lenders is $\bar{\kappa}_l^t - \bar{\kappa}_{l-1}^t$; specifically,

$$\kappa_l^t = \begin{cases} p_t^0 - \lambda - (c^t - \delta V^{t+1} + E[\omega_{(2)}^t | n^t = 2]), & l = 2, \\ E[\omega_{(2)}^t | n^t = l-1]) - E[\omega_{(2)}^t | n^t = l]), & l = 3, 4, \cdots, N. \end{cases} \tag{3.7}$$

A borrower with search cost κ_l^t is indifferent between searching for l versus $l-1$ quotes.

The cost of searching l lenders is $(l-1)\kappa^t$ because the home bank is always in the choice set. The borrower chooses n^t to maximize the net benefit from searching:

$$n^t = \text{argmax}_l \, \bar{\kappa}_l^t - (l-1)\kappa^t, \quad l = 1, 2, \cdots, N. \tag{3.8}$$

The initial home bank quote p_0^t influences the search intensity n^t through the expected gain from searching. When p_0^t is low enough, the borrower might never choose a choice set of size l because she expects a loss from searching $\bar{\kappa}_l^t < 0$. The borrower would search $l \geq 2$ lenders for some realization of κ^t if and only if the following condition is satisfied:

$$\bar{\kappa}_l^t/(l-1) > \kappa_{l+1}^t. \tag{3.9}$$

This condition implicitly requires $\bar{\kappa}_l^t > 0$. If condition (3.9) fails then $\forall \kappa^t < \bar{\kappa}_l^t/(l-1)$, $\kappa^t < \kappa_{l+1}^t$; the borrower prefers searching $l+1$ rather than l lenders as the expected marginal gain outweighs the search cost.

Let $\bar{l}^t$ be the smallest number that satisfies condition (3.9). Given the search cost distribution, $H(\cdot)$, the home bank expects the borrower searching l lenders with the following probabilities:

$$Pr(n^t = l) = \begin{cases} 1 - H(\bar{\kappa}_{\bar{l}^t}^t/(\bar{l}^t - 1)), & l = 1 \\ 0, & l < \bar{l}^t \ \& \ l \neq 1 \\ H(\bar{\kappa}_{\bar{l}^t}^t/(\bar{l}^t - 1)) - H(\kappa_{\bar{l}^t+1}^t), & l = \bar{l}^t \\ H(\kappa_l^t) - H(\kappa_{l+1}^t), & l > \bar{l}^t \ \& \ l < N \\ H(\kappa_N^t), & l = N. \end{cases} \tag{3.10}$$

The home bank can therefore choose p_0^t to influence $\bar{l}^t$ and hence the borrower's search probabilities.

For simplicity of exposition, from now on assume in equilibrium that the optimal initial offer p_0^{t*} is high enough such that $\bar{l}^t = 2$. In this case, the home bank's belief is that every size l of the choice set will be reached with positive probability as set out in equation (3.10). In what follows we derive conditions under which the belief system is well defined and consistent with the home bank's optimal initial quote choice in equilibrium. It is straightforward to adapt to cases where in equilibrium $\bar{l}^t > 2$.

Anticipating the borrower's search probabilities and the corresponding auction outcomes, the home bank chooses initial quote p_0^{t*} to maximize its expected profit:

$$\begin{aligned}\max_{p_0^t}\ & [1 - H(\bar{\kappa}_2^t(p_0^t))](p_0^t - c^t + \delta W^{t+1}) + [H(\bar{\kappa}_2^t(p_0^t)) - H(\kappa_3^t)]E[\pi_h^{t*}|n^t = 2] \\ & + \sum_{l=3}^{N-1}[H(\kappa_l^t) - H(\kappa_{l+1}^t)]E[\pi_h^{t*}|n^t = l] + H(\kappa_N^t)E[\pi_h^{t*}|n^t = N],\end{aligned} \tag{3.11}$$

where $E[\pi_h^{t*}|n^t = l]$ is the profit that the home bank expects to obtain in the negotiation stage conditional on the choice set size $n^t = l$. It can be calculated as

$$\begin{aligned}E[\pi_h^{t*}|n^t = l] &= Pr_{h^t}\{E[p^{t*} - (c^t + \omega_{h^t})|n^t = l, \omega_{h^t} - \lambda \leq \omega_{-h^t}] + \delta W^{t+1}\} + (1 - Pr_{h^t})\delta L^{t+1} \\ &= E\left[\max\{\omega_{-h^t} - (\omega_{h^t} - \lambda), 0\} \mid n^t = l\right] + \delta L^{t+1}.\end{aligned}$$

We can then write the first order condition for the optimal initial quote:

$$p_0^t = \frac{1 - H(\bar{\kappa}_2^t(p_0^t))}{H'(\bar{\kappa}_2^t(p_0^t))} + c^t - \delta V^{t+1} + E\left[\max\{\omega_{-h^t} - (\omega_{h^t} - \lambda), 0\} \mid n^t = 2\right].$$

Replacing p_0^t on the left-hand side using equation (3.6) and rearranging, the first order condition is equivalent to:

$$\bar{\kappa}_2^t(p_0^t) = \frac{1 - H(\bar{\kappa}_2^t(p_0^t))}{H'(\bar{\kappa}_2^t(p_0^t))}. \tag{3.12}$$

Assuming the Mills ratio on the right-hand side is monotonically decreasing, we can obtain a unique solution $\bar{\kappa}_2^{t*}$, and hence the optimal initial quote:[24]

$$p_0^{t*} = \bar{\kappa}_2^{t*} + \lambda + c^t - \delta V^{t+1} + E[\omega_{(2)}^t | n^t = 2]. \tag{3.13}$$

3.3.5 Continuation Values

We can now summarize the results obtained from the initial-quote stage and the negotiation stage. Given the choice set n^t and the state vector s^t, the equilibrium price from the auction p^{t*} is described in equation (3.5). Knowing the payoff from accepting p_0^t and the expected payoff from searching n^t lenders, the borrower chooses n^t optimally to solve the search problem (3.8). Anticipating the search intensity (equation (3.10)) and the corresponding auction outcome, the home bank chooses the optimal initial quote p_0^{t*} to maximize its expected profit.

Stepping back to the previous period, $t - 1$, anticipating the borrower's and the banks' equilibrium strategies in the following period, the lenders can calculate the continuation value of winning and losing. Specifically, the continuation value of winning is just the sum of the home bank's expected profit from retaining the borrower in the initial quote stage and the expected profit from the negotiation

[24]Condition (3.9) must be satisfied for $l = 2$, so that given the optimal initial quote the borrower's search probabilities are well defined and the same as those being used in the home bank's optimization problem (3.11). Specifically, the condition $\bar{\kappa}_2^{t*} > \kappa_3^t$ must hold.

stage if the borrower decides to search:

$$\begin{aligned} W^t &= [1 - H(\bar{\kappa}_2^{t*})](p_0^{t*} - c^t + \delta W^{t+1}) + [H(\bar{\kappa}_2^{t*})) - H(\kappa_3^t)]E[\pi_h^{t*}|n^t = 2] \\ &\quad + \sum_{l=3}^{N-1}[H(\kappa_l^t) - H(\kappa_{l+1}^t)]E[\pi_h^{t*}|n^t = l] + H(\kappa_N^t)E[\pi_h^{t*}|n^t = N] \\ &= \delta L^{t+1} + [1 - H(\bar{\kappa}_2^{t*})]\left(\bar{\kappa}_2^{t*} + E\left[\max\{\omega_{-h^t} - (\omega_{h^t} - \lambda), 0\} \mid n^t = 2\right]\right) \\ &\quad + \sum_{l=2}^{N} Pr(n^t = l)E\left[\max\{\omega_{-h^t} - (\omega_{h^t} - \lambda), 0\} \mid n^t = l\right]. \end{aligned} \tag{3.14}$$

In order to calculate the continuation value of losing, consider a representative non-home bank j with idiosyncratic match value ω_j^t. ω_{-j}^t denotes the first order statistic among the $n^t - 1$ variables $(\{\omega_k^t\}_{k \neq j, k \neq h^t}, \omega_{h^t} - \lambda)$. The continuation value of losing can be written as:

$$L^t = \delta L^{t+1} + \sum_{l=2}^{N} Pr(n^t = l)\frac{l-1}{N-1}E\left[\max\left\{\omega_{-j}^t - \omega_j^t), 0\right\} \mid n^t = l\right], \tag{3.15}$$

where the fraction $\frac{l-1}{N-1}$ is the probability that bank j gets selected into the choice set conditional on $n^t = l$. Therefore, the net continuation value of winning, i.e., the investment incentive is:

$$
\begin{aligned}
V^t &= W^t - L^t \\
&= [1 - H(\bar{\kappa}_2^{t*})] \left(\bar{\kappa}_2^{t*} + E\left[\max\left\{\omega_{-h^t} - (\omega_{h^t} - \lambda), 0\right\} \mid n^t = 2\right]\right) \\
&\quad + \sum_{l=2}^{N} Pr(n^t = l) E\left[\max\left\{\omega_{-h^t} - (\omega_{h^t} - \lambda), 0\right\} \mid n^t = l\right] \\
&\quad - \sum_{l=2}^{N} Pr(n^t = l) \frac{l-1}{N-1} E\left[\max\left\{\omega_{-j}^t - \omega_j^t), 0\right\} \mid n^t = l\right].
\end{aligned}
\tag{3.16}
$$

The investment incentive, V^t is purely determined by the search cost distribution $H(\cdot)$, the idiosyncratic cost distribution $G(\cdot)$, the switching cost λ, and the number of available lenders N, which are all assumed to be invariant over time.[25] As a result of the symmetric cost structure, V^t does not depend on future continuation values.

Intuitively, the investment incentive is always increasing in the switching cost λ. It tends to be smaller, however, if the lenders expect search costs to be small, because retaining the borrower becomes less likely in the next period. Other things equal, as $G(\cdot)$ gets more dispersed, the expected marginal saving from searching an extra bank increases, the borrower obtains more quotes, and the home bank finds it harder to retain the borrower; V^t tends to be smaller. Its relationship with N is more subtle. If search costs are expected to be low on average, higher N implies more quotes and more competition in the next period, hence V^t would be lower. However, if search costs are very high on average, the borrower would not obtain more quotes even though N increases. L^t decreases because the chance of being selected in the next period gets smaller, therefore V^t could even increase in N.

[25]It is straightforward to allow for exogenous trends in these model primitives.

3.4 Identification

This section provides an argument for non-parametric identification of our model. In section 3.5, we specify a parametric version in order to make use of observed heterogeneity across borrowers in estimation. The model consists of five primitives: (i) the common cost distribution $F(\cdot|x_i)$, the realization of which is the same for all lenders providing a mortgage to borrower i, but may vary across borrowers due to both observed and unobserved heterogeneity; (ii) the idiosyncratic cost distribution $G(\cdot|x_i)$; (iii) the search cost distribution $H(\cdot|x_i)$; (iv) the switching cost, $\lambda_i = \Lambda(x_i)$; and (v) the lenders' discount factor, δ.

In the data, we observe a cross section of borrowers (new borrowers and first-time renewers) with (i) observed borrower characteristics (x_i), (ii) the number of lenders available in a borrower's local market (N_i), (iii) the home-bank identity, the chosen lender's identity, and (iv) the contract price offered by the final winner (p_i^*). From these observables we wish to recover the model primitives.

There are two main identification challenges. The first is to disentangle the randomness originating from the funding cost distributions $F(\cdot|x_i)$ and $G(\cdot|x_i)$, and the search cost distribution $H(\cdot|x_i)$ from the observed contract price distribution. The price distribution for borrowers staying with their home banks is a mixture of accepted initial quotes and auction prices, while the price distribution for switchers is determined by the search intensity and the corresponding auction outcome. Neither is ideal for separating out the search-cost distribution from the lending-cost distributions.

The second challenge is to disentangle the common cost and idiosyncratic cost distributions. In the auction, due to the random common cost component, lenders' cost for providing a mortgage are not independent. This prevents us from using standard identification strategies under the independent private values framework. Indeed, Athey and Haile (2002) suggests that identification fails in such case without observing all the bids.

In order to get around the negative identification result, we need to put more restrictions on the model primitives. We rely crucially on an exclusion restriction assumption:

Assumption 1. *(Exclusion Restriction)*
There exists some observable z_i that influences the switching cost $\lambda_i = \Lambda(x_i, z_i)$ but not the other model primitives $F(\cdot|x_i)$, $G(\cdot|x_i)$, and $H(\cdot|x_i)$.[26]

For the sake of a more transparent identification argument, we also make the following assumption to abstract away from some observable differences across borrowers:

Assumption 2. *x_i are the same across contracts.*

Further, we make some assumptions on the support of the distributions. These are not imposed in the estimation.

Assumption 3. *(Support Assumptions)*
(i) The common cost distribution $F(\cdot)$ has bounded support $[\underline{c}, \bar{c}]$.

[26] An example of z_i would be the qualifying rate for renewers under the mortgage stress tests, which exogenously influences the switching cost without changing the other model primitives. We discuss the stress tests in more detail in the counterfactual experiments.

(ii) The idiosyncratic cost distribution $G(\cdot)$ is mean 0, and has bounded support $[\underline{\omega}, \bar{\omega}]$.

(iii) The number of available lenders N_i has full support ranging from 2 to $\bar{N}$.

(iv) There is enough variation in z, such that $\lambda = \Lambda(z)$ ranges from 0 to $+\infty$.

The following assumptions imposed on model primitives are needed to ensure that (1) we are dealing with a unique equilibrium, and (2) in equilibrium the home bank's belief is correct that every size l of the choice set will be reached with positive probability as set out in equation (3.10).

Assumption 4.

(i) The Mills ratio $\frac{1-H(\kappa)}{H'(\kappa)}$ is monotonically decreasing.

(ii) In equilibrium, $\kappa_2^* > \kappa_3$.

In what follows, we first focus on markets where only two banks are available to identify all model primitives except for the search cost distribution, and then use price variation across markets with different N to pin down the search cost distribution.

3.4.1 Identification of Switching Costs

We focus on the sub-sample of borrowers located in markets with only two available lenders ($N = 2$). In such markets, if we observe that a borrower switches lenders, she must have rejected the home bank's initial quote and searched. Denote the home bank and rival bank in the choice set as h and r, respectively. In the data, we observe the empirical distribution of prices for borrowers financing with their home bank, P_h, and prices for borrowers switching to the rival bank, P_r. P_h is a mixture of accepted initial quotes, P_{h1}, and prices paid by borrowers who search but don't switch, P_{h2}.

Using the support Assumptions 3(i) and 3(ii), for borrowers with observable z, $P_h(z)$ and $P_r(z)$ are bounded from below by the following prices:

$$\begin{aligned} \underline{P}_h(z) &= \underline{c} + \underline{\omega} + \Lambda(z) - \delta V(z), \\ \underline{P}_r(z) &= \underline{c} + \underline{\omega} - \delta V(z). \end{aligned} \tag{3.17}$$

$\Lambda(z)$ is therefore identified from $\underline{P}_h(z) - \underline{P}_r(z)$.

3.4.2 Identification of the Search Probability and Discount Factor

Given Assumption 4(i) and Equation (3.12), all borrowers face the same unique search cost threshold $\kappa_2^* = \bar{\kappa}_2^*$. Therefore, all borrowers accept the home bank initial offer with probability $1 - H(\kappa_2^*)$.

Now consider the sub-sample of borrowers in 2-bank markets with $\Lambda(z) = 0$, who are equally likely to stay or switch in the negotiation stage. In the data, we observe the empirical probability that borrowers search **and** switch:

$$Pr(\text{search, switch}|\Lambda(z) = 0) = Pr(\kappa < \kappa_2^*)Pr(\omega_h > \omega_r) = H(\kappa_2^*)/2.$$

Therefore, the probability of searching $H(\kappa_2^*)$ is identified.

Similarly, we can write the empirical probability of search and switch for the sub-sample of borrowers with $\lambda = \Lambda(z)$:

$$Pr(\text{search, switch}|\lambda = \Lambda(z)) = H(\kappa_2^*)Pr(\omega_h - \Lambda(z) > \omega_r).$$

Therefore $Pr(\omega_h - \omega_r < -\Lambda(z))$ is identified. By varying $\Lambda(z)$, the distribution of the idiosyncratic cost difference $(\omega_h - \omega_r)$ is identified.

Now go back to the sub-sample of borrowers with $\Lambda(z) = 0$ in 2-bank markets. We can write the expected values of the switchers' prices, the home-bank initial offers, and the loyal borrowers' prices,

$$E[P_r|\Lambda(z) = 0] = E[c] + E[\max\{\omega_h, \omega_r\}] - \delta V(z),$$
$$E[P_{h1}|\Lambda(z) = 0] = E[c] + E[\max\{\omega_h, \omega_r\}] - \delta V(z) + \kappa_2^*,$$
$$E[P_h|\Lambda(z) = 0] = [1 - H(\kappa_2^*)]E[P_{h1}|\Lambda(z) = 0] + \frac{H(\kappa_2^*)}{2}E[P_r|\Lambda(z) = 0].$$

The last equality holds because the expected values of P_r and P_{h2} are the same when switching costs are zero. In the data, the average prices of P_r and P_h are observed. We can therefore use the above equations to derive κ_2^*.

Given the search cost threshold κ_2^*, the search probability $H(\kappa_2^*)$, the switching cost $\Lambda(z)$, and the distribution of $(\omega_h - \omega_r)$, the investment incentive conditional on observable z can be calculated:

$$V(z) = [1 - H(\kappa_2^*)]\left(\kappa_2^* + E[\max\{\omega_r - (\omega_h - \lambda), 0\}]\right) + H(\kappa_2^*)\Lambda(z).$$

The discount factor δ is identified from the lower bounds of prices in Equation (3.17) by varying z. The lower bound on funding costs $\underline{c} + \underline{\omega}$ is also identified.

3.4.3 Identification of Cost Distributions

We have now identified the probability of searching $H(\kappa_2^*)$. It will help to separate out the distribution of initial home bank offers P_{h1} from the observed loyal borrowers' price distribution P_h.

We again focus on the sub-sample of borrowers with $\Lambda(z) = 0$ in 2-bank markets. The distribution of P_h is given by:

$$Pr(P_h \leq p|\Lambda(z) = 0) = [1 - H(\kappa_2^*)]Pr(P_{h1} \leq p|\Lambda(z) = 0) + \frac{H(\kappa_2^*)}{2}Pr(P_r \leq p|\Lambda(z) = 0),$$

because the distributions of P_{h2} and P_r are the same when switching costs are zero. The distribution of P_{h1} is identified because the empirical distributions of P_h and P_r are known. Therefore the distribution of the common cost distribution $F(\cdot)$ is identified from the following equation:

$$\begin{aligned} Pr(P_{h1} \leq p|\Lambda(z) = 0) &= Pr(c + E[\max\{\omega_h, \omega_r\}] - \delta V(z) + \kappa_2^* \leq p|\Lambda(z) = 0) \\ &= Pr\left(c \leq p - (E[\max\{\omega_h - \omega_r, 0\}] - \delta V(z) + \kappa_2^*)|\Lambda(z) = 0\right). \end{aligned}$$

In addition, using the empirical distribution of switcher's prices, we can identify the distribution of $c + \max\{\omega_h, \omega_r\}$:

$$\begin{aligned} Pr(P_r \leq p|\Lambda(z) = 0) &= Pr(c + \max\{\omega_h, \omega_r\} - \delta V(z) \leq p|\Lambda(z) = 0) \\ &= Pr(c + \max\{\omega_h, \omega_r\} \leq p + \delta V(z)|\Lambda(z) = 0). \end{aligned}$$

The distribution of $\max\{\omega_h, \omega_r\}$ is identified using a standard deconvolution approach.[27] The parent distribution, $G(\cdot)$ is therefore also identified.

[27] See Diggle and Hall (1993) for a more detailed discussion. Krasnokutskaya (2011) applies the deconvolution methods in identifying auction models with unobserved heterogeneity.

3.4.4 Identification of the Search Cost Distribution

From above, we have already obtained some information about the search cost distribution: the search cost threshold κ_2^* and the search probability $H(\kappa_2^*)$ in 2-bank markets. Recall that κ_2^* is solely determined by the search cost distribution as shown in Equation (3.12). Therefore, in all markets ($N \geq 2$), borrowers will accept the initial quotes with probability $(1 - H(\kappa_2^*))$, and search multiple quotes with probability $H(\kappa_2^*)$. The search cost distribution is identified at the cut-off value κ_2^*. By varying N, we can identify the search cost distribution at more cut-off values $(\kappa_{l>2}(z))$. And by varying the observable z, the set of cut-off values will also change, tracing out most of the search cost distribution. However, $H(\cdot)$ cannot be identified for search costs above κ_2^*, because borrowers who draw such high search costs would all simply accept the home banks' initial offers, making them observationally equivalent.

Consider a sub-sample of borrowers with observable z in 3-bank markets. The cut-off value $\kappa_3(z)$ can be calculated using Equation (3.7) because we know the idiosyncratic cost distribution $G(\cdot)$ and the switching cost $\Lambda(z)$. The overall switching probability is

$$\begin{aligned} Pr(\text{switch}) = Pr(n = 2)Pr(\omega_{-h} \leq \omega_h - \Lambda(z)|n = 2) \\ + Pr(n = 3)Pr(\omega_{-h} \leq \omega_h - \Lambda(z)|n = 3), \end{aligned}$$

where all probabilities are also conditional on $\lambda = \Lambda(z)$ and $N = 3$. Given that the search probabilities $Pr(n = 2|\lambda = \Lambda(z), N = 3)$ and $Pr(n = 3|\lambda = \Lambda(z), N = 3)$ add up to $H(\kappa_2^*)$, they are identified. Note that the probability of searching only 2 banks in the 3 bank market can also be written as:

$$\begin{aligned} Pr(n=2|\lambda=\Lambda(z), N=3) &= Pr(n=2|\lambda=\Lambda(z), N=\bar{N}) \\ &= H(\kappa_2^*) - H(\kappa_3(z)). \end{aligned}$$

Therefore, $H(\cdot)$ is also identified at the point $\kappa_3(z)$. Inductively, $H(\kappa_4(z))$ is identified using the sub-sample of borrowers with switching cost $\Lambda(z)$ in the 4-bank markets, and so forth. By varying z and hence $\Lambda(z)$, we can obtain different sets of cut-off values $\kappa_l(z)$, tracing out the search cost distribution $H(\cdot)$ evaluated at these points.

3.5 Empirical Specification

Consider a borrower i in a market with N_i available lenders looking to originate or renew a mortgage with loan size $\$M_i$. We model the common cost of all lenders for providing the mortgage over the 5-year term as $M_i c_i$, which naturally depends on the loan size. The per-unit common cost c_i is assumed to be drawn from a normal distribution $N(\boldsymbol{x_i}\boldsymbol{\beta}, \sigma_c^2)$. The vector $\boldsymbol{x_i}$ includes some observed borrower characteristics (outstanding amount, credit score, and amortization), 5-year bond rate, median income at the FSA level in 2016, quarterly housing transaction count at FSA level, quarterly average sale price at FSA level, year fixed effects, and location fixed effects.[28] The loan size M_i is normalized so that the per-unit common cost measures the cost of a $\$100,000$ mortgage.

Denote borrower i's mortgage loan size at origination (origination amount) as M_i^1.

[28] A location is defined by the first digit of a borrower's postal code. Quebec and Ontario are split into 3 and 5 regions, respectively. Other provinces have a single region.

M_i^1 is the same as M_i for new borrowers, but greater than M_i for renewers, because renewers have paid down some of their outstanding balance over the first 5-year term. We model the idiosyncratic cost for lender j in the negotiation stage as $M_i^1\omega_{i,j}$, where $\omega_{i,j}$ is drawn *i.i.d.* from a type-1 extreme value distribution T1EV$(\gamma\sigma_\omega, \sigma_\omega)$.[29] M_i^1 captures the effect of loan-size on costs. Fixing the loan size to the amount at origination has two benefits. First, the origination amount can be seen as more informative about a borrower's profitability beyond the mortgage product. The second benefit is technical: it prevents the outstanding amount from entering into the lenders' pricing problem.[30]

The switching cost is assumed to be a linear function of borrower's age, credit score, and median income at FSA level in 2016. For new borrowers, we allow the switching cost from a pre-mortgage relationship to be different from the regular switching costs for renewers:

$$\lambda_i = M_i^1 \times (\lambda_0 + \lambda_{credit}\text{Credit}_i + \lambda_{inc}\text{Income}_i + \lambda_{age}\text{Age}_i + \lambda_{new}).$$

The search cost is assumed to follow an exponential distribution with its mean

[29] γ is the Euler constant, and the idiosyncratic cost distribution in this specification has mean 0.

[30] Otherwise, the outstanding amount becomes a payoff-relevant state variable. Lenders' net continuation value of winning will depend on their expectation on the outstanding balance at renewal and hence depend on their belief regarding the winning bank's identity and winning bid. This would result in multiple equilibria in the negotiation stage. This problem will often be negligible because the difference in expected outstanding balance after 5 years due to different interest rates is small.

determined by the borrower's age, credit score, and the FSA-level median income:

$$H_i(\kappa) = 1 - exp(-\frac{\kappa}{\alpha_i}), \quad \alpha_i = exp(\alpha_0 + \alpha_{credit}\text{Credit}_i + \alpha_{inc}\text{Income}_i + \alpha_{age}\text{Age}_i).$$

Given the parametric assumptions, we can analytically solve the search probabilities, the net continuation value of winning, the home bank's optimal initial offer, the auction price in the negotiation stage conditional on stay/switch and the choice set size. We can then derive the likelihood contribution of each borrower (loyal or switch). Since we do not observe the number of quotes, we first construct the likelihood function conditional on the choice set, n_i, and then integrate out n_i using the search probabilities. We estimate the model by maximum likelihood. The likelihood function is derived in Appendix B.

3.6 Estimation Results

3.6.1 Model Estimates

Table 3.3 displays the maximum likelihood estimates from both our benchmark dynamic model and a static model that restricts the lenders' discount factor $\delta = 0$. In the dynamic model, we estimate a lender discount factor of 0.73 over a 5-year span, which translates into an annual discount factor of 0.94. The likelihood ratio test rejects the static model at the 0.1% significance level.

The mortgage loan size is normalized to be measured in \$100,000. The estimated parameters, measured in \$1,000, describe how the interest cost of a \$100,000 mortgage is determined by the observable characteristics and the random shocks. For example, in the first row $\sigma_c = 0.8534$ implies that the standard deviation of the common cost for lending $\$100,000$ over a 5-year term is $853.4. In what follows, we discuss the economic magnitude of the model estimates.

Lending Costs. The standard deviation of the idiosyncratic cost distribution is $187.6, which is only about one fifth of the standard deviation of the common cost shock.[31] This means that most of the unexplained price variation should be attributed to unobserved borrower heterogeneity rather than by idiosyncratic differences across banks. This is consistent with Allen et al. (2019).

The dispersion of the idiosyncratic cost distribution is key for understanding the borrowers' search decisions. When banks' idiosyncratic costs vary a lot, borrowers are more likely to find banks with low enough price to switch to, and hence they are more likely to search. Figure 3.1 shows a median borrower's expected marginal benefit of adding an extra bank to the choice set. The expected marginal benefit decreases as the choice set gets bigger, declining from over $450 for $n = 1$ to around $30 for $n = 9$.

Turning to the mean of the common cost component, the coefficient estimates all have intuitive interpretations. The mean common cost is decreasing in credit score and increasing in bond rate. On average, mortgages with bigger outstanding balance or shorter amortization cost less per unit. The lending costs are on average lower in markets with higher income level, higher house price, and greater volume of housing transactions.

Search Costs. Since we do not observe the search cost realizations and search

[31] The standard deviation of a T1EV distributed random variable is $\sigma_\omega \pi/\sqrt{6}$.

Table 3.3: Maximum Likelihood Estimation Results

	Dynamic Model		Static Model	
	Estimate	(S.E.)	Estimate	(S.E.)
Cost shocks				
σ_c	0.8534	(0.003)	0.8563	(0.0031)
σ_ω	0.1463	(0.0022)	0.1503	(0.0021)
Search cost				
α_0	-1.0557	(1.2617)	-0.0527	(0.0185)
α_{credit}	-0.0478	(0.1597)	-0.1203	(0.0026)
α_{income}	0.1199	(0.0166)	0.1120	(0.0083)
α_{age}	-0.0667	(0.0353)	-0.1533	(0.0111)
Switching cost				
λ_0	-0.1422	(0.0952)	-0.1705	(0.0283)
λ_{credit}	0.0471	(0.0123)	0.0528	(0.0029)
λ_{income}	-0.0062	(0.0018)	-0.0071	(0.0017)
λ_{age}	0.0269	(0.0043)	0.0282	(0.0033)
λ_{new}	-0.1452	(0.008)	-0.1488	(0.0079)
Mean common cost				
Constant	11.8419	(0.3811)	11.4375	(0.2735)
Credit score	-0.1122	(0.0103)	-0.1392	(0.0095)
Outstanding amount	-0.0891	(0.0108)	-0.0383	(0.0067)
Bond rate	1.7871	(0.0315)	1.7728	(0.0303)
Amortization	0.4965	(0.0097)	0.5074	(0.0073)
Income	-0.0126	(0.004)	-0.0191	(0.0031)
House price (log)	-0.1072	(0.0313)	-0.0879	(0.0239)
Transaction no. (log)	-0.0425	(0.0056)	-0.0495	(0.005)
Discount factor δ	0.7278	(0.1118)		
Log likelihood	45,625.00		45,277.99	
LR test ($H_0 : \delta = 0$)			25.98	

Note: outstanding amount is measured in \$100,000, credit score is measured in 100, median income at FSA level is measured in \$10,000, amortization is measured in 5 years, and bond rate is measured in percentage points. We include year fixed effects and region fixed effects. We trim the bottom and top 1% of observations in terms of interest rate. Each specification has 16,377 observations. The likelihood ratio test rejects the null hypothesis $\delta = 0$ at significance level 0.1%. The critical value of $\chi^2(1)$ distribution associated with the 0.1% significance level is 10.83.

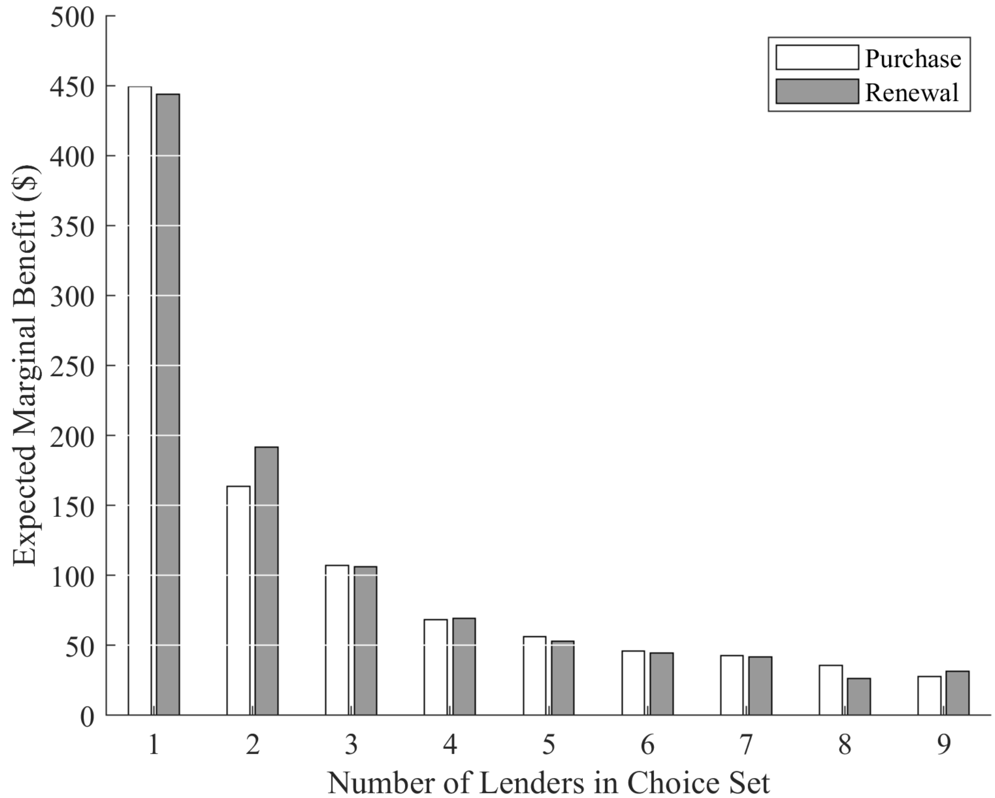
decisions, we use a simulated sample to help understand the estimated search cost distribution. We simulate 100,000 contracts by sampling borrowers' observable characteristics from the empirical distribution and drawing search cost and lending cost shocks from the estimated distributions. We then solve the equilibrium outcomes and summarize the variables of interest in Table 3.4. See subsection 3.6.2 for more details about the simulation process.

Searchers, on average, have much lower per-bank search costs than do non-searchers: \$204 versus \$972. On average they obtain 3.4 quotes, one of which is from the home bank. Figure 3.2 shows how average search costs vary by credit score, income and age. The income level at the borrower's FSA plays a major role in shaping the search costs. This is intuitive because the search and negotiation process is time-consuming and time costs can be approximated by borrowers' income. In addition, search costs are on average decreasing in credit score and age, possibly due to more leverage and experience in negotiations.

Switching Costs. Renewers on average face much higher switching costs than new borrowers, \$656 versus \$293, as shown in Table 3.4. This is reasonable given the extra fees and inconvenience incurred from transferring mortgages across lenders relative to, say, a credit card. Figure 3.2 shows, for a \$100,000 mortgage, the variation of renewers' switching costs by credit score, income and age. Switching costs are increasing in credit score and age, while the FSA-level income does not seem to have significant impact. This is also intuitive since the switching process itself is not very time-consuming.[32]

[32] The new provider would handle the mortgage-transfer process on behalf of the borrower.

Figure 3.1: Expected Marginal Benefit of Adding an Extra Bank



Note: for each choice set size $n = 1, 2, 3, \cdots, 10$, we simulate 10,000 purchase (renewal) mortgage contracts for a borrower with median observable characteristics and calculate the average cost of financing (equilibrium price plus switching cost incurred). The expected marginal benefit of adding an extra bank to a choice set of size n is calculated as the change in cost of financing.

3.6.2 Goodness of Fit

In order to understand the goodness of fit for the structural model, we simulate mortgage contracts by feeding observable transaction characteristics into the estimated model. If the model approximates well the underlying data generating process, the

Table 3.4: Summary Statistics of Variables of Interest

	mean	sd	p25	p50	p75
Search cost	485.7	545.8	130	317	652
Searcher	203.6	164.7	78	173	294
Non-searcher	971.8	625.5	578	796	1,166
Number of quotes	2.5	1.9	1	2	3
Searcher	3.4	1.9	2	3	4
Switching cost	478.2	315.6	244	402	642
New Purchase	293.2	171.4	175	260	370
Renewal	655.9	320.3	426	604	824
Investment incentive	774.4	278.9	572	738	937

Note: we simulate 100,000 mortgage contracts by sampling borrowers' observable characteristics from the empirical distribution and drawing lenders' cost shocks and borrowers' search cost shocks from the estimated distributions. We then solve the lenders' equilibrium pricing and borrowers search decisions.

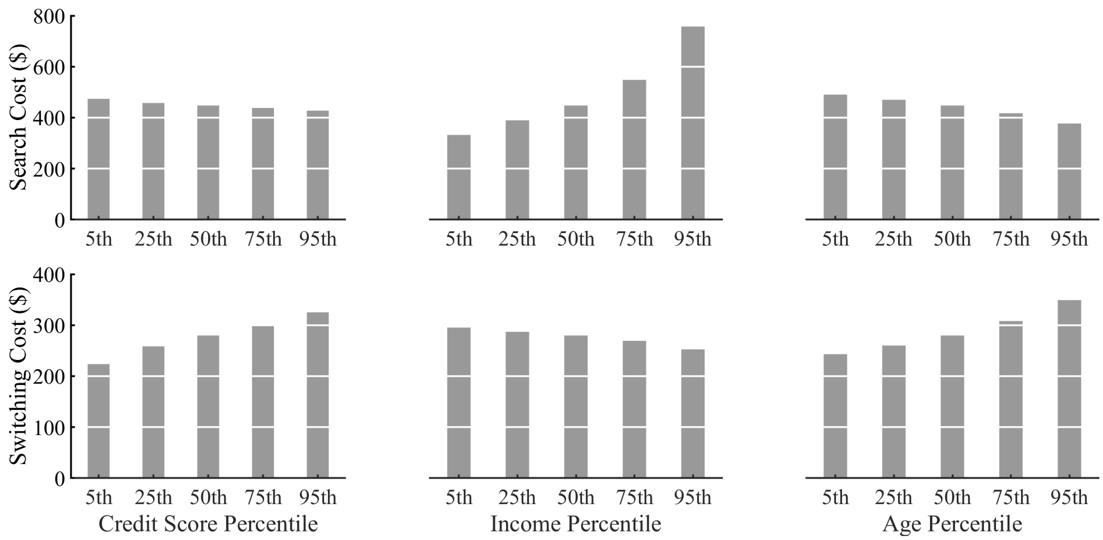
simulated sample should be similar to the data. We obtain the observed and simulated samples as follows:

1. With replacement, randomly draw 100,000 mortgage contracts (including the observable transaction characteristics and the equilibrium outcomes) from the data to form the observed sample.

2. Use the observed sample, keep the transaction characteristics (x_i, h_i, N_i), and draw individual shocks $(c_i, \boldsymbol{\omega}_i, \kappa_i)$ from the estimated lending cost and search cost distributions.

3. Solve the model and compute the equilibrium outcomes for the simulated sample: the home bank's initial offer $p^*_{i,0}$, the borrower's search decision n^*_i, the

Figure 3.2: Search and Switching Costs by Credit Score, Income, Age



Each subplot shows the variation of search (switching) cost by credit score, income, and age, respectively, while fixing the other two factors at median level. For example, the upper middle plot displays the average search cost level for borrowers with median credit score and median age but at different income percentiles. The lower middle plot shows the switching cost per $100,000 mortgage for renewers with median credit score and median age but at different income percentiles.

borrower's switch decision, and the winning price p_i^*.

Table 3.5 summarizes the equilibrium outcomes from both the observed and simulated samples. Panel A shows the comparison for new borrowers' contracts, while Panel B is for renewal contracts. Overall, the unconditional distributions of interest rate, interest cost, and switch indicator from the simulated sample closely match those from the observed sample. The model seems to over-predict the median interest rate (2.69% vs. 2.73% for purchase, and 2.70% vs. 2.77% for renewal) and the share of switching borrowers, but matches very well the interest cost distribution.

In Table 3.6, we assess the model's ability to generate the same correlations

Table 3.5: Summary Statistics for Observed and Simulated Samples

	Observed Sample			Simulated Sample		
	Panel A: New Purchase					
	Rate(%)	Interest Cost	1(Switch)	Rate(%)	Interest Cost	1(Switch)
mean	2.75	31.88	0.259	2.75	31.85	0.283
sd	0.25	15.30	0.438	0.26	15.21	0.450
p25	2.59	21.03		2.57	20.91	
p50	2.69	29.51		2.73	29.62	
p75	2.90	40.21		2.91	40.24	
	Panel B: Renewal					
	Rate(%)	Interest Cost	1(Switch)	Rate(%)	Interest Cost	1(Switch)
mean	2.79	23.94	0.120	2.80	23.95	0.136
sd	0.27	11.83	0.325	0.28	11.79	0.343
p25	2.60	15.48		2.60	15.43	
p50	2.70	21.98		2.77	21.96	
p75	2.99	30.36		2.98	30.42	

Note: the observed sample is obtained by drawing 100,000 mortgage contracts from the data with replacement. The simulated sample is obtained by keeping the transaction characteristics the same as the observed sample while drawing shocks from the estimated distributions. Unit for interest cost is $1,000.

between equilibrium outcomes (e.g. interest rate and switching decision) and transaction characteristics as those observed in the data. Regression estimates in columns (1)-(2) are based on the observed sample, while those in columns (3)-(4) are from the simulated data. The first exercise ((1) and (3)) regresses interest rates on the observable characteristics and the contract purpose (new purchase, loyal renewal, or switch renewal). We also report estimates from linear probability models for the switch decisions in columns (2) and (4).

Table 3.6: Reduced-form Regressions Using Observed and Simulated Samples

	Observed Sample		Simulated Sample	
	(1)	(2)	(3)	(4)
	Rate	1(Switch)	Rate	1(Switch)
Credit score	-2.20***	-0.034***	-2.52***	-0.040***
	(0.099)	(0.0017)	(0.099)	(0.0020)
Outstanding amount	-2.28***	0.025***	-2.51***	0.042***
	(0.067)	(0.0014)	(0.072)	(0.0015)
Bond rate	0.42***	0.00015*	0.38***	0.000071
	(0.0037)	(0.000068)	(0.0034)	(0.000071)
Amortization	1.29***	0.025***	1.14***	0.011***
	(0.087)	(0.0014)	(0.088)	(0.0015)
Income	-0.18***	-0.00043	-0.14***	-0.0064***
	(0.036)	(0.00076)	(0.038)	(0.00078)
Age	0.29***	-0.031***	0.23***	-0.030***
	(0.054)	(0.00095)	(0.055)	(0.0010)
House price (log)	-1.42***	0.0033	-2.21***	-0.0092
	(0.24)	(0.0049)	(0.25)	(0.0051)
Transaction no. (log)	-0.97***	0.0028*	-0.85***	0.0021
	(0.068)	(0.0012)	(0.064)	(0.0013)
No. of lenders	-0.62***	0.0035***	-0.085*	0.0054***
	(0.044)	(0.00084)	(0.042)	(0.00084)
Loyal Renewal	3.71***		5.10***	
	(0.15)		(0.15)	
Switch Renewal	-5.30***		-9.70***	
	(0.24)		(0.26)	
R^2	0.492	0.038	0.496	0.033

Note: There are 100,000 observations in each sample. We include year and region fixed effects. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The estimated model almost perfectly reproduces the correlation between interest rates and observable transaction characteristics, except that it underestimates the coefficient on the number of lenders. We obtain similar R^2's from the observed and simulated samples, indicating that similar amount of rate dispersion cannot be explained by the observable characteristics. The structural model attributes this unexplained portion to the random draws of the structural shocks.

However, the average loyalty premium predicted by the model is somewhat higher than that estimated from the observed sample. This is partly explained by the fact that we have trimmed mortgage contracts with extreme values for interest rates in the observed sample but not in the simulated one.

The estimated model also performs well in terms of matching the correlation between borrowers' switching decisions and the observable transaction characteristics. The linear probability regression estimates from the simulated sample display the same signs as those obtained from the observed sample, and many of the coefficient estimates are close in magnitude.

3.7 Counterfactual Experiments

In this section we conduct three counterfactual experiments to investigate (i) the effects of search and switching frictions on borrowers' and banks' payoffs, (ii) the implications of dynamic versus static settings for merger-studies, and (iii) the impacts from the recently adopted mortgage stress tests in Canada.

The first two experiments highlight the importance of understanding lenders' dynamic pricing strategies. A static model overestimates the benefit of removing search and switching costs because it ignores the changes in lenders' investment incentives and pricing dynamics. For the same reasons a static merger simulation overestimates the impact of a merger, and a retrospective merger evaluation using only purchase contracts underestimates the impact of a merger on renewals.

Finally, we examine the potential impact of a recent government-mandated mortgage affordability test, which requires borrowers to satisfy tighter debt-to-income constraints. Importantly, uninsured renewers are required to pass the test if they choose to switch lenders but not if they renew with their current lender. As a result, the test increases their switching costs and potentially increases their interest rates. In the counterfactual experiment, we find that about 12% of new borrowers in our sample would fail the test if they were subject to it at renewal. For these borrowers, the stress test would substantially increase the home bank's market power and lead to a 10% increase in interest costs.

3.7.1 Frictionless Markets

To better understand the effect of search and switching frictions on the prices that the borrowers pay and the profits that lenders obtain, we compare the equilibrium outcomes in the current environment to environments in which at least one of the market frictions is eliminated. We simulate 100,000 borrowers' new purchase contracts and their subsequent renewal contracts as follows:

1. Using only the sub-sample of new borrowers, draw observable characteristics (x_i, h_i, N_i) from the empirical distribution.
2. Draw individual shocks $(c_i, \boldsymbol{\omega}_i, \kappa_i)$ from the estimated distributions.

3. Solve the model and compute the equilibrium outcomes: the lenders' investment incentive V_i, the home bank's initial offer $p^*_{i,0}$, the borrower's search decision n^*_i, the winning price in the negotiation stage p^*_i, the winning bank's identity, the total cost of financing the mortgage including the search and switching costs, the implied interest rate, the remaining balance at renewal, the present discounted value of profits expected by the home bank and rival banks.
4. Assume the borrower's characteristics remain the same at renewal. Given the remaining balance and amortization period, repeat steps 2 and 3 to obtain the equilibrium outcomes for the subsequent renewal contract.

Benchmark. Table 3.7 summarizes the equilibrium outcomes from different counterfactuals. Column (1) shows the results simulated from our benchmark model with both search and switching frictions. An immediate observation is that with all observables (except for outstanding amount and amortization) unchanged, borrowers are less likely to switch due to the higher switching costs. The profits expected by the home bank and the rival banks are higher in the dynamic setting than in the static one, because forward-looking banks take into account future profits.

Table 3.7: The Effects of Removing Market Frictions, Dynamic/Static Predictions

	(1) Benchmark		(2) Search Cost		(3) Switching Cost		(4) No Frictions	
	Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static
	Panel A: New Purchase Contracts							
Loan size	253.985	253.985	253.985	253.985	253.985	253.985	253.985	253.985
Interest cost	31.842	31.790	32.049	31.662	31.553	31.089	31.717	31.052
Total cost	32.120	32.084	32.253	31.878	31.755	31.303	31.717	31.052
Interest rate	2.748	2.740	2.766	2.729	2.723	2.677	2.737	2.674
$\text{Profit}_{\text{home}}$	0.556	0.570	0.453	0.406	0.192	0.143	0.193	0.070
$\text{Profit}_{\text{rival}}$	0.243	0.127	0.542	0.192	0.592	0.284	0.967	0.348
$\text{Profit}_{\text{total}}$	0.798	0.697	0.995	0.599	0.785	0.427	1.159	0.417
V	0.784	—	0.337	—	0.270	—	0.000	—
# quotes	2.494	2.459	2.583	2.547	6.583	6.583	6.583	6.583
Pr(switch)	0.286	0.278	0.405	0.402	0.692	0.684	0.831	0.831
	Panel B: Renewal Contracts							
Loan size	214.037	214.019	214.111	213.973	213.934	213.768	213.993	213.755
Interest cost	26.090	26.072	26.050	25.653	25.708	25.279	25.706	25.039
Total cost	26.398	26.390	26.251	25.863	26.022	25.600	25.706	25.039
Interest rate	2.756	2.753	2.751	2.709	2.716	2.668	2.715	2.643
$\text{Profit}_{\text{home}}$	0.815	0.832	0.435	0.389	0.348	0.318	0.172	0.069
$\text{Profit}_{\text{rival}}$	0.158	0.065	0.485	0.194	0.429	0.178	0.863	0.348
$\text{Profit}_{\text{total}}$	0.973	0.896	0.920	0.583	0.777	0.497	1.034	0.417
V	0.801	—	0.329	—	0.290	—	0.000	—
# quotes	2.528	2.531	2.604	2.602	6.583	6.583	6.583	6.583
Pr(switch)	0.153	0.149	0.406	0.406	0.446	0.437	0.830	0.830

Note: We simulate 100,000 purchase contracts using the estimated dynamic model by randomly drawing observable characteristics from the sub-sample of new borrowers. From these new purchase contracts, we obtain the average loan size (outstanding amount), interest cost, total cost (interest cost plus search and switching costs incurred), present discounted value of profits expected by the home bank, rival banks, and their sum, investment incentive (V), number of quotes, and switching probability. Assume all these purchase contracts are renewed after 5 years with all observable characteristics remaining the same but smaller outstanding balance and shorter amortization. We then simulate the equilibrium outcomes for these subsequent renewal contracts. Repeat the simulation experiment using the estimated static model. Column (2) shows the simulated outcomes from models where search cost is the only friction. Column (3) is obtained by simulating contracts from models where switching cost is the only friction. Column (4) assumes neither search cost nor switching cost is present. All monetary values are measured in $1,000.

Removal of Switching Costs. Column (2) describes a counterfactual where switching costs are eliminated and the only friction is the search costs. Relative to the benchmark dynamic setting, new borrowers at origination are worse off in terms of the interest costs and total cost for financing a mortgage (interest cost plus the search and switching costs incurred). Lenders compete less aggressively because the net continuation value of winning V decreases. Renewers are better off in terms of the total cost, saving an average of \$146. Assuming borrowers are patient enough, with an annual discount factor of at least 0.87, the savings in the renewal periods would make up for the increase in total cost at origination (\$134).[33] On the lenders' side, home banks suffer from the removal of switching costs while rival banks are better off. In sum, banks' total expected profit from a new borrower is higher without switching costs, but no bank is willing to lower the costs of switching for its own customers because it only benefits rival banks. Therefore, if the banks were to endogenously determine the level of switching costs, they face the prisoner's dilemma.[34]

The static model predicts unambiguous gains for the borrowers, both at origination and at renewal. On average, new borrowers and renewers receive a 0.4% and 1.6% reduction in interest costs, respectively, when we remove switching costs.

[33] The consumer discount factors estimated from other empirical studies are often much lower. For example, Dubé et al. (2014) use survey data on Blu-ray player adoption and estimate an average annual discount factor of 0.7. See Frederick et al. (2002) and Yao et al. (2012) for a more detailed review on consumer discount rates.

[34] A word on collateral charge mortgages, which have recently increased in popularity. This type of mortgage is readvanceable, meaning that banks can lend more after closing without the need to refinance. This increases switching costs, however, since they are non-transferable and hence borrowers need to incur legal fees (around \$1,500) to switch lenders. Our model suggests that this is ultimately unprofitable since future rents are competed away at origination.

The savings in total costs due to the elimination of switching frictions are even bigger. The static model overestimates the benefit of eliminating switching frictions on borrowers, because it ignores the fact that lenders compete less aggressively for a borrower that might easily switch to a rival bank in future periods. Predictions from the static model would support policies aimed at promoting competition through reducing switching costs. However, the dynamic model suggests that such policies may not achieve the intended goal.

Removal of Search Costs. Column (3) describes the counterfactual world where search costs are eliminated and only switching costs are present. In the simulation borrowers no longer receive an initial home-bank quote. Rather, they search all the available lenders and on average obtain four more quotes than the benchmark sample. The benefit of the extra free quotes are significant. In a dynamic world, borrowers enjoy 1.1% and 1.4% decreases in total costs at origination and at renewal, respectively. The static model predicts even higher savings in total costs: 2.4% at origination and 3.0% at renewal.[35] The static model again overestimates the benefit of removing search costs because it ignores the reduction in lenders' investment incentives.

Removal of Both Frictions. Column (4) describes the counterfactual world where both switching costs and search costs are eliminated. In this case, the lenders' net continuation value of winning becomes zero. In a dynamic world, new borrowers' total costs on average decrease by 1.3%. Renewers benefit even more, paying 2.6%

[35] Allen et al. (2019) estimate that search frictions lead to a loss in consumer surplus equivalent to 2% of the interest costs. The effect is smaller because they assume borrowers obtain quotes from all available lenders once they decide to search. Eliminating search frictions do not help searchers obtain more quotes.

lower total costs than the benchmark sample. The static model predicts 3.2% and 5.1% reductions in total costs at origination and at renewal, respectively.

In summary, the static model overestimates the benefit of removing search and switching costs because it ignores the changes in lenders' investment incentives. In the dynamic world, removing the switching costs alone–depending on how patient borrowers are–could potentially disadvantage the new borrowers in terms of the discounted total costs over the entire mortgage life. Removing the search costs, however, is much more helpful because it directly promotes competition among more lenders and results in lower prices.

3.7.2 Merger Analysis: Taking Dynamics into Account

This section highlights the importance of modeling lenders' dynamic pricing strategies when conducting policy analysis. We focus on mergers. Due to search costs, an average borrower only obtains 2.5 quotes in a market where there are on average 6.6 lenders. This means that for most borrowers their search decisions and choice sets are unaffected by a merger. The impact of the merger on prices is indirectly reflected in changes in the lenders' investment incentives and may not be noticeable. In order to best compare the merger analysis in a static versus dynamic setting, we therefore focus on the sub-sample of borrowers who would be most affected by a merger. We investigate the effect of a two-bank merger on borrowers who obtain multiple quotes in three-bank markets.

Ex Ante Merger Simulation

We simulate 100,000 contracts from the sub-sample of borrowers in 3-bank markets using the estimated models under both status quo and counterfactual market structures, holding fixed the realizations of all random shocks. We abstract from the cost-efficiency effects that might come from the merger, and assume that the merged entity's idiosyncratic cost realizations are just random draws from the two merging parties' idiosyncratic cost shocks. In the simulated samples, we drop all borrowers who do not search for multiple quotes under the status quo market structures. Table 3.8 summarizes the equilibrium outcomes pre- and post-merger in both dynamic and static models.

Pre-merger, borrowers on average obtain 2.4 quotes. Post-merger, most of the borrowers would still search and obtain 2 quotes. The dynamic model predicts that new borrowers and renewers see a 0.3% and 0.4% increase in interest costs post-merger, respectively. The static model predicts a 0.4% and 0.6% increase, respectively. The static merger simulation overestimates the merger impact because it ignores the fact that lenders' investment incentive increases by 8% for new purchase contracts, and by 7% for renewal contracts. Lenders expect less competition in future renewal periods and hence compete more aggressively ex ante to attract customers. The higher investment incentive dampens the size of the merger impact predicted by the static model.

Table 3.8: The Impact of a Merger

	Dynamic		Static	
	Before	After	Before	After
	Panel A: New Purchase Contracts			
Outstanding amount	216.721	216.721	216.693	216.693
Interest cost	27.173	27.248	27.109	27.227
Investment Incentive	0.720	0.779	—	—
# quotes	2.446	1.989	2.425	1.989
Pr(switch)	0.386	0.312	0.374	0.304
	Panel B: Renewal Contracts			
Outstanding amount	159.884	159.884	159.884	159.884
Interest cost	19.746	19.826	19.733	19.859
Investment Incentive	0.697	0.745	—	—
# quotes	2.452	1.990	2.476	1.981
Pr(switch)	0.163	0.120	0.158	0.115

Note: From the sub-sample of borrowers living in markets where only three banks are available, we simulate 100,000 contracts under both the current market structure and the counterfactual market structure after a merger. We keep only borrowers obtaining multiple quotes before the hypothetical merger (about 63% of the sample). All monetary values are measured in $1,000.

Retrospective Merger Evaluation

Now consider a different case in which a merger has already happened. A researcher wants to perform a retrospective evaluation to investigate the price impact. Suppose the researcher ignores the pricing dynamics and mistakenly believes that lenders price renewal contracts in the same way as they do for new borrowers. The researcher may conduct the retrospective merger evaluation using only the new borrowers' contracts, which can often be accessed more easily. See, for example, Allen et al. (2014a).

A retrospective merger evaluation based on new borrowers (panel A of Table 3.8) would estimate a 0.3% increase in interest costs post-merger. It *underestimates* the true merger impact, because it ignores the fact that renewers suffer more from having one less available lender (renewers' interest costs on average increase by 0.4%). After the merger, finding a lender with low enough cost to switch to becomes much harder. Due to higher switching costs, renewers are more likely to be retained by their home bank and therefore pay relatively high prices.

3.7.3 The Impact of Mortgage Stress Testing

Since 2008, mortgage rates in Canada have been declining and reached record lows in 2016. Low interest rates stimulated housing market activities, with home buyers taking out larger mortgage loans than they otherwise could afford. Worried about large-scale mortgage default, the Department of Finance and the Office of the Superintendent of Financial Institutions (OSFI) introduced a series of four stress tests between 2010 and 2018 to improve underwriting standards and ensure that borrowers could meet their mortgage-payment obligations in case of rising rates.[36]

One of the debt-to-income constraints imposed by the stress test is that borrowers' gross debt-servicing ratio (GDS) cannot exceed 39%. GDS is defined as follows:

$$\text{GDS} \equiv \frac{\text{Mortgage Payment} + \text{Property Tax} + \text{Heating Cost} + 50\% \text{ of Condo Fee}}{\text{Gross Income}}.$$

[36]See Chapter 4 for a more detailed discussion of the mortgage stress tests and Allen et al. (2017a) for a discussion of the effectiveness of macroprudential policies in Canada.

The mortgage payment in the formula, however, is not the actual payment that the borrower would make according to the negotiated contract rate. Rather, it is a hypothetical mortgage payment calculated using a 'qualifying' rate, which is approximately 200 bps more than the median contract rate.[37]

All four stress tests are applied to borrowers at origination. For the latest stress tests, introduced in 2018, uninsured borrowers are even subject to it at renewal should they switch to a different bank.[38] In a speech on the stress test, OSFI emphasized that it does "not want borrowers who do not meet the increased underwriting standards to become the focus of price competition among lenders."[39] As we will show in the simulation experiment, this leads to some unintended consequences: (1) home banks enjoy a much greater incumbency advantage, and (2) unqualified renewers suffer from higher switching costs and therefore higher interest rates.

In the counterfactual experiment, we use only a sub-sample of new borrowers and show the impact of the stress test on these borrowers if they suddenly became subject to the stress test at renewal. At renewal, we work out the borrowers' remaining balances and remaining amortization periods, and assume that all of the other observable borrower characteristics stay the same. Using the borrowers' reported income and the qualifying rate (5.19%), we calculate the the maximum loan amount

[37]The qualifying rate is determined by the mode of the big 6 banks' posted rates on 5-year fixed-rate mortgages. For insured mortgages the qualifying rate is just the modal 5-year posted rate. For uninsured mortgages, the qualifying rate is the greater of the modal rate and the contract rate plus 200 bps. As of January 2020, the 5-year modal rate is 5.19%, about 220 bps higher than the average contract rate.

[38]Insured borrowers do not face a stress test at renewal because the loans are free of default risk from the point of view of the lender.

[39]See `https://www.osfi-bsif.gc.ca/Eng/osfi-bsif/med/sp-ds/Pages/CR20190205.aspx`.

for which they could qualify.[40]

If a borrower's remaining balance at renewal is smaller than the qualified amount, she can pass the stress test and the equilibrium outcomes of this borrower are unaffected. However, if the remaining balance at renewal exceeds the qualified amount, the borrower fails the stress test and will need to pay down the excess balance in order to switch lenders. We interpret this as an exogenous one-time increase in switching costs faced by unqualified renewers. We approximate the switching cost increment by the cost required to pass the stress test. More specifically, we assume that unqualified borrowers can borrow from private lenders at an annual interest rate of 10%.[41] The switching cost increase can then be approximated by the cost of borrowing the excess amount from the private lenders.[42]

[40] Assume the GDS constraint holds with equality and the other maintenance costs in the formula amount to 1% of the initial loan size, the maximum hypothetical mortgage payment is obtained. Along with the qualifying rate and amortization, the maximum qualified loan amount can be calculated.

[41] According to the financial comparison platform Ratehub.ca, interest rates offered by private lenders range from 10% to 18%.

[42] An alternative for some borrowers is to switch from a federally regulated lender to a credit union, which are provincially regulated. Credit unions are not subject to the uninsured stress test to the same extent as federally regulated lenders. Banks in our model are symmetric, therefore allowing for this substitution would require extending the model. In the U.S. there has been mounting documentation that following increased capital regulation on banks post-financial crisis, borrowers have switched from traditional lenders to non-traditional ones. See for example Buchak et al. (2018).

Table 3.9: The Impact of Mortgage Stress Testing

	All Renewers		Unqualified Renewers	
	No Test	Test	No Test	Test
Outstanding amount	213.409	213.409	307.337	307.337
Qualified amount	321.109	321.109	270.819	270.819
Income	74.469	74.469	65.915	65.915
Interest cost	26.015	26.448	36.814	40.527
Total cost	26.322	26.737	37.250	40.810
Interest rate	2.756	2.785	2.695	2.947
$\text{Profit}_{\text{home}}$	0.814	1.227	1.068	4.610
$\text{Profit}_{\text{rival}}$	0.157	0.146	0.250	0.158
# quotes	2.526	2.526	2.873	2.873
Pr(switch)	0.153	0.135	0.177	0.021
Switching cost	0.693	1.119	1.018	4.670
Obs	100,000	100,000	11,643	11,643

Note: We draw 100,000 mortgage contracts with replacement from the sub-sample of new borrowers and assume their contracts are renewed after 5 years with all observable characteristics remaining the same but smaller outstanding balance and shorter amortization. We then simulate the equilibrium outcomes for the subsequent renewal contracts both in the regular case and the in the case when borrowers are subject to stress test. The last two columns focus on the subset of borrowers who would fail the stress test. All monetary values are measured in $1,000.

Table 3.9 summarizes the impact of the stress test on the renewal contracts. In the simulated sample of all borrowers at renewal, they are largely unaffected by the stress test. Most of the renewers have their remaining mortgage balance well below the qualified amount. On average, renewers are slightly less likely to switch and experience a 3 bps increase in interest rates due to the stress test.

However, the impact on unqualified renewers are much more significant. About 12% of borrowers would fail the stress test at renewal. Their remaining balance exceeds the maximum qualified amount by $36,518. These affected renewers need to incur more than four times of their original switching costs to pass the stress test and switch to rival banks. As a result, home banks are able to retain about 98% of the affected renewers, and charge higher prices. The unqualified renewers on average experience a 25 bps increase in interest rates and a 10% increase in interest costs.[43]

Note that the current stress test only applies to uninsured renewers, while the borrowers in our sample are all insured. However, we expect the impact on uninsured renewers would be even more significant. As pointed out in Chapter 4, the share of high loan-to-income mortgages in the uninsured sector is higher than the share in the insured sector. Therefore uninsured renewers are more likely to be constrained by the stress tests.

3.8 Conclusion

We develop a framework for investigating dynamic competition in markets where price is negotiated between one customer and multiple firms repeatedly. Using contract level data for the Canadian mortgage market, we provide evidence of an "invest-then-harvest" pricing pattern: lenders offer relatively low interest rates to attract new borrowers and poach rivals' existing customers, and then at renewal in some instances, charge interest rates which can be higher than what may be available through other lenders in the marketplace. We build a dynamic model of price negotiation with search and switching frictions to capture the key market features.

Our counterfactual experiments highlight the importance of understanding lenders'

[43]This unintended consequence is similar to the one studied by Amromin and Kearns (2014) in the U.S. mortgage market, where they find that the Home Affordability Refinancing Program strengthened the incumbency advantage in mortgage refinancing by reducing home lenders' underwriting risk more than the rival lenders' and hence increased home lenders' market power.

dynamic pricing strategies in policy evaluations. A static model overestimates the benefit of eliminating search and switching costs because it ignores the changes in lenders' investment incentives and pricing dynamics. For the same reasons, static merger analyses also yields biased results: (i) static merger simulation overestimates the merger impact, and (ii) retrospective merger evaluation using only purchase contracts underestimates the merger impact on renewals. In our experiment that simulates the impact of mortgage stress tests, we find 12% of new borrowers in our sample would fail if they were subject to it at renewal. For these unqualified borrowers, the stress test would substantially increase the home bank's market power and lead to a 10% increase in interest costs.

Chapter 4

The Strategic Response of Banks to Macroprudential Policies: Evidence from Mortgage Stress Tests in Canada

4.1 Introduction

In the wake of the financial crisis, macroprudential regulations targeting vulnerabilities on the borrower side of the mortgage market have been widely adopted. Mortgage eligibility criteria such as restrictions on loan-to-value (LTV) and debt-to-income (DTI) ratios have been used to contain leverage growth and mortgage default risk. Based on a survey of bank regulators from 36 countries in 2010, Crowe et al. (2013) show that about half had implemented policies restricting LTV and DTI ratios.

In this chapter we provide evidence suggesting that banks may have behaved strategically to limit the potency of macroprudential policies implemented in Canada by manipulating an interest-rate benchmark. Since 2008, interest rates in Canada have been declining, reaching record lows in 2016. The low rates stimulated housing demand, allowing borrowers to take out larger mortgage loans than they otherwise could have afforded. Worried that large-scale mortgage default might occur should rates rise quickly causing sharp increases in mortgage payments, the Department of Finance and the Office of the Superintendent of Financial Institutions (OSFI) introduced a series of four stress tests between 2010 and 2018 (described in detail in Section 4.3) that applied restrictions to a greater and greater set of mortgage products, the first two targeting short-term mortgages, and the last two, longer-term contracts.

As with similar stress examinations implemented in the UK and in Hong Kong, the Canadian tests aimed to restrict qualification for mortgages by tightening DTI constraints. DTI restrictions in Canada specify that a borrower's mortgage payment, housing expenses, and other debt obligations cannot account for more than a fixed percentage of their gross income. Prior to the implementation of the stress tests, mortgage payment calculations were usually performed using the interest rate specified in the contract. This changed under the new rules. Henceforth, borrowers were required to satisfy the DTI restrictions even if the interest rate were to rise to the level of the *qualifying rate*, derived weekly from the mode of the 5-year fixed rates posted by the largest six banks in Canada (i.e. the Big 6).[1]

We examine how the Big 6 Canadian banks adjusted their 5-year posted rates to influence mortgage qualification in the period surrounding the policy changes. The

[1]The Big 6 includes Bank of Montreal (BMO), Bank of Nova Scotia (BNS), Canadian Imperial Bank of Commerce (CIBC), National Bank of Canada (NBC), Royal Bank of Canada (RBC), and Toronto-Dominion Bank (TD).

new qualifying rate should typically be higher than the contract (transaction) rate, since most consumers negotiate to receive a discount off the posted rate (see Allen et al. (2014b) and Allen et al. (2019)). Therefore, if the big banks continued to set 5-year posted rates in the same way as before the implementation of the stress tests and if consumers stuck with their originally preferred mortgage products, the new qualification rules should have had a significant impact on access to credit, as intended by the government. Indeed, Bilyk and teNyenhuis (2018) show that mortgage activity slowed somewhat following the stress tests. The question we pose in this chapter is whether this slowdown was muted by a strategic response on the part of the Big 6 banks, whose interests were not aligned with those of the government. Tougher qualification standards lower the demand for the banks' products and they are less concerned about mortgage-market overheating. Moreover, many of the mortgages issued are government-insured, such that banks do not bear the costs of consumer default. As a result, the Big 6 had incentive to manipulate their 5-year posted rates in an effort to limit the impact of the stress tests and ensure that consumers continued to borrow from them.

The objective of our empirical analysis is to test for a strategic reaction on the part of the Big 6 to the rule changes. To do so, we use publicly available data from the Bank of Canada and CANNEX Financial Exchanges, and adopt a difference-in-difference framework. We compare the Big 6's 5-year posted rates before and after the implementation of each of the stress tests. Since other factors could influence the evolution of the 5-year rate over this period, we control for general trends in rate setting using the 3-year posted rate, which was not directly affected by the policy changes. In order to account for funding cost changes for both 3-year and 5-year contracts, we use spreads (between posted rates and funding costs) to generate our dependent variables.

Our main outcome variable of interest is the modal 5-year posted rate, since it influences the qualification rule. Our findings reveal patterns consistent with manipulation on the part of the Big 6. Following the last two stress tests, which targeted longer-term contracts (5-year terms and up), the Big 6 restrained the qualifying rate from rising in accordance with the surging funding cost. Specifically, we find that, relative to the 3-year modal spread, the 5-year modal spread fell by 43 basis points (bps).

In addition to the mode, we also investigate the impact on mean 5-year spread to see whether the banks' individual incentives differ from their collective incentives. If qualifying standards are based on transaction rates, individual lenders have incentive to keep posted rates as high as possible: a higher posted rate allows banks to more easily engage in price discrimination (Allen et al. (2014b) and Allen et al. (2019)) and also to impose higher prepayment penalties, since these are a function of the posted rate. We find that, relative to 3-year spreads, the mean 5-year spread fell by only 13 bps. The fact that the mean fell by so much less than the mode provides evidence that a tension exists between the banks' individual incentives to keep rates high and their collective incentive to lower rates for qualification purposes.

Finally, we also analyse how the Big 6 manipulated the qualifying rate following each of the first two stress tests that targeted short-term contracts – those with fixed-rate terms of less than 5 years and all variable-rate mortgages. Importantly, although the tests targeted short-term contracts, the qualifying rate was nonetheless determined based on the modal 5-year rate in order to make qualification more difficult (since the 5-year mode is higher than the 3-year mode). In light of our findings regarding the second set of stress tests, one might expect the Big 6 would also manipulate the qualifying rate downwards to make qualification easier following the first set of tests. However, we find the opposite: the mode of the 5-year spreads increased by more than 30 bps relative to the 3-year spreads. Why would the Big 6 have incentive to make it even harder for borrowers to qualify for short-term mortgages? The explanation is intuitive: borrowers could easily circumvent the tests by switching to untested longer-term (5-year) contracts sold by the Big 6, and the banks had an incentive to encourage this switching because longer-term contracts are more profitable.[2] Therefore, although the Big 6 appeared to toughen qualification standards following the first set of tests, in fact their actions benefited themselves and did not help to curb credit expansion.

Turning back to the second set of stress tests, we use our estimates to provide insight into what would have happened to the decline in mortgage originations had the banks *not* manipulated the qualifying rate after the tests came into force. To do so we investigate what fraction of contracts originated prior to the implementation of the second set of tests would fail under different qualifying rates. Specifically, we use the loan-to-income distribution to back out the DTI distribution assuming a

[2]Longer-term contracts are more profitable because they feature higher price ceilings and more room for price discrimination. Furthermore, income constrained borrowers failing the stress test for short-term mortgages may have more inelastic demand for longer-term contracts, allowing the Big 6 to achieve higher spreads. We discuss the relative profitability of 5-year contracts further in Section 4.3.

particular qualifying rate, and we then calculate the share of mortgages that fail to meet the DTI restriction. This share varies with the qualifying rate, and our back-of-the-envelope calculation suggests that 25% more insured mortgages and 12.4% more uninsured mortgages would have failed the stress tests had the qualifying rate not been manipulated.

In the next section, we discuss related literature. In Section 4.3, we provide more details regarding the Canadian mortgage market and the mortgage rate stress tests. Section 4.4 presents the data. Section 4.5 describes the empirical methodology and the results. Section 4.6 investigates the impacts of manipulation. Section 4.7 concludes.

4.2 Related Literature

Our paper contributes to a recent literature that studies the effectiveness of housing-related macroprudential policies.[3] Igan and Kang (2011) find that tightening constraints on LTV and DTI helped to cool down the housing market in Korea. Krznar and Morsink (2014) find that tighter restrictions on LTV and DTI ratios helped to rein in house-price and mortgage-credit growth in Canada from 2000 to 2012. Corbae and Quintin (2015) suggest that the exogenous relaxation of DTI restrictions facilitated more originations of high-LTV mortgages during the US housing boom and accounted for more than 60% of the foreclosure rate spike afterwards. Greenwald (2018) also argues that the loosening of DTI restrictions played a major role in the recent financial crisis, and he advocates macroprudential regulations limiting

[3]See Damar and Molico (2016) for a general overview of macroprudential policy tools and their effectiveness in stabilizing the financial system based on both Canadian and international evidence.

DTI rather than LTV as a more effective policy for stabilizing housing and mortgage markets. Allen et al. (2017b) show that over the period 2005 to 2011 borrowers in Canada were more likely wealth-constrained than income-constrained, hence they responded more to policies targeting LTV than to DTI policies. Benetton (2018) suggests that LTV constraints lower borrower defaults, but have negative influence on origination and consumer surplus. Moreover, when interacted with a risk-weighted capital regulation, the LTV restrictions could reduce big lenders' equity buffers and increase systemic risk. There are also some cross-country studies using rich panel data to investigate the effectiveness of macroprudential policies and in particular housing related tools (e.g. Vandenbussche et al. (2015), Zhang and Zoli (2016), Cerutti et al. (2017), Akinci and Olmstead-Rumsey (2018), and McDonald (2018)).

We are related to the literature examining frictions that limit the transmission of various policies to the housing market. Benetton et al. (2019) describe how the transmission of the UK's funding for lending scheme is impaired by price-discriminatory behavior on the part of banks. In Agarwal et al. (2017) product design is shown to have limited the effectiveness of the Home Affordable Modification Program, while in DiMaggio et al. (2017) contract design influences monetary policy pass through.

Our paper is closely related to a new empirical literature that studies agents' strategic responses to macroprudential policies. Han et al. (2017) show that the impact of a macroprudential policy aimed at cooling the housing market was dampened due to home sellers' strategic responses. They also point out that macroprudential policy assessment should take into account the strategic responses of the agents affected. DeFusco et al. (2019) study the impacts of the Dodd-Frank "Ability-to-Repay" rule in the US mortgage market.[4] The rule incentivized lenders to qualify borrowers using DTI restriction because otherwise the cost of origination would be higher. They find that mortgages violating the DTI constraint were priced higher, reflecting the pass-through from higher origination cost. More interestingly, they find lenders rationed their mortgage credit towards the low DTI ratio market, and hence further reduced the quantity of high-DTI mortgages, reinforcing the policy impact. Agarwal et al. (2018) show that in response to a macroprudential policy that tightens collateral requirements in Singapore, lenders relaxed mortgage qualification along other unregulated dimensions to avoid excess funding liquidity. Acharya et al. (2019) find that following the introduction of macroprudential regulations limiting the LTV and DTI for residential mortgages in Ireland, banks encouraged qualified borrowers to borrow closer to the limits by offering lower rates, reallocated more credit supply towards business loans, and increased their holdings of risky securities.

More broadly, we are related to a small, but growing, literature studying banks' manipulative conduct. A number of recent papers study the manipulation of benchmark interest rates by banks. Abrantes-Metz et al. (2012), Snider and Youle (2012), Youle (2014), Duffie and Stein (2015), Chen (2017), and Bonaldi (2017) all study manipulation of the London Inter-bank Offered Rate (LIBOR), which is an estimate of the interbank borrowing costs for unsecured funds and is calculated daily as a trimmed mean of quotes submitted by a fixed panel of large banks. That being said, unlike in the LIBOR scandal, there is no evidence in our case that banks directly

[4] See also Bhutta and Ringo (2015), Gissler et al. (2016) and D'Acunto and Rossi (2017) for analysis of the response to this policy.

communicated with each other in order to coordinate rates. Gambacorta et al. (2019) find that in the Italian mortgage market, due to profit maximizing incentives lenders might offer distorted advice regarding what type of mortgage (fixed or variable rate) suits best the borrower's need. Agarwal et al. (2015) show that lenders effectively colluded with borrowers regarding collateral valuations in order to be able to lend them larger amounts than dictated by capital providers, a behavior that they point out is consistent with the assertion in Zingales (2012) that lenders bent the rules during the lead up to the crisis in order to increase credit supply. Benzarti (2019) studies the reaction of lenders to the introduction of additional borrower protections as a result of the Dodd-Frank Act. His results show that lenders reduced interest rates in order to avoid the additional protection measures.

Finally, it should be noted that our individual-level stress tests focus on the household balance sheet and act by tightening borrowers' DTI constrains. This is different from both the sort of tests proposed in Bhutta et al. (2019) to gauge the soundness of the mortgage market as a whole, and also from the bank-level stress tests enacted in response to the crisis (see Kapinos et al. (2018) and Hirtle and Lehnert (2015) for surveys).

4.3 The Mortgage Stress Tests

In Canada, most mortgage contracts have 25-year amortization periods. But mortgage terms are much shorter, ranging between one and ten years, during which time the interest rate is either fixed or variable. For illustration purposes, we define mortgage-terms with interest rates fixed for 5 years or greater as *longer-term* contracts, and the remainder as *short-term* contracts (1- to 4-year fixed-rate contracts and all variable-rate contracts). The most popular mortgage term is for 5-years at a fixed rate. The 5-year term is also more profitable for lenders than is a shorter-term contract. Longer-term contracts are characterized by higher price ceilings and more room for price discrimination. In addition, interest rates had been declining from 2010 to 2016, and so long-term contracts were more profitable in such an environment.[5]

The largest six banks, also known as the Big 6, are the most influential players in the residential mortgage market. Together, they fund about 90% of mortgages originated by federally regulated chartered banks, and held approximately 70% of the total outstanding balances of residential mortgage credit as of January 2018. Each of the Big 6 lenders publishes "posted rates" for fixed-rate mortgage products of various term length on its website. The posted rate acts as a price ceiling, with borrowers normally able to negotiate with banks to receive discounts off the posted rate and make mortgage payments according to the actual contract rates.[6] Even if many borrowers do not pay the posted rate, it can nonetheless play an important role. It is the starting point for negotiation, it signals the interest cost, and it is used for prepayment penalty calculations. Most importantly for our purposes, with the implementation of the stress tests, the mode of the Big 6's 5-year posted rates is now

[5]There is anecdotal evidence suggesting that lenders prefer to have borrowers locked into long-term contracts when they expect a declining rate trend. In January 2019, the largest bank in Canada, RBC, lowered its best available discounted 5-year fixed rate by 15 bps, while raising the variable rate by 25 bps. This move made the 5-year fixed rate contract much more attractive than its short-term mortgage products.

[6]See Allen et al. (2014b) and Allen et al. (2019) for more details.

used as a benchmark in the mortgage stress tests to assess borrowers' affordability.

Since 2008, mortgage rates in Canada have been declining and reached record low levels in 2016. The low interest rates stimulated housing market activities, with home buyers taking out larger mortgage loans than they otherwise could afford. Concerned about the stability of the housing market, the Government (Department of Finance and OSFI) made a number of changes to mortgage underwriting rules in recent years. To ensure that borrowers could meet their mortgage-payment obligations in case of rising rates, four borrower qualification tests were introduced. These rules are known as the "Stress Tests." Similar tests were implemented in Hong Kong in 2010 and in the UK in 2014, with mortgages tested for their ability to withstand higher interest rates by verifying that borrowers could afford a 200 or 300 basis points increase in rates.

The first two Canadian stress tests targeted mortgages with fixed-rate terms of less than 5 years and all variable-rate mortgages (short-term contracts). The stress test implemented in 2010 (henceforth STI1) covered only insured mortgages, while the test enacted in 2012 (henceforth STU1) extended the reach to include uninsured mortgages originated by federally regulated financial institutions (FRFIs). The final two stress tests covered the remaining mortgage products: fixed-rate mortgage terms of 5 years or more (longer-term contracts). Again, the first test implemented in 2016 applied to insured mortgages (henceforth STI2), while the 2018 test applied to the uninsured sector (henceforth STU2). For the first three stress tests, the qualifying rate was set as the greater of the contract rate and the modal 5-year posted rate determined by the Big 6. For the last one, the qualifying rate could be even higher:

the greater of the contract rate *plus 200 basis points* and the modal rate. All four stress tests are applied to borrowers at origination. For STU2, uninsured borrowers are even subject to stress test at renewal should they renew their mortgage with a different bank. Table 4.1 describes the stress tests in more detail.

Table 4.1: Stress Tests

Stress Test	Timing	Targeted Sector	Coverage
STI1	Announced: Feb 16, 2010 Effective: Apr 19, 2010	Insured Mortgages	Variable-rate Fixed-rate: 1-4 years
STU1	Proposed: Mar 19, 2012 Announced: Jun 21, 2012 Effective: Jun 21, 2012	Uninsued Mortgages from FRFIs	Variable-rate Fixed-rate: 1-4 years
STI2	Announced: Oct 3, 2016 Effective: Oct 17, 2016	Insured Mortgages	Variable-rate Fixed-rate: 1-10 years
STU2	Proposed: Jul 7, 2017 Announced: Oct 17, 2017 Effective: Jan 1, 2018	Uninsued Mortgages from FRFIs	Variable-rate Fixed-rate: 1-10 years

Note: After STU1 was announced, OSFI required full implementation no later than fiscal year-end 2012 (Oct 31, 2012 for large Schedule 1 banks and Dec 31, 2012 for most of the other FRFIs), but expected FRFIs to comply as soon as possible.

To understand the essence of the stress tests, we need to first define two debt-to-income ratios that lenders and mortgage insurers use to assess a borrower's ability to afford a mortgage contract: gross debt-servicing ratio (GDS) and total debt-servicing ratio (TDS). These are defined as follows:

$$\text{GDS} \equiv \frac{\text{Mortgage Payment} + \text{Property Tax} + \text{Heating Cost} + 50\% \text{ of Condo Fee}}{\text{Gross Income}},$$

$$\text{TDS} \equiv \frac{\text{All Expenses in GDS} + \text{Other Debt Obligations}}{\text{Gross Income}}.$$

Prior to the introduction of the stress tests, insured mortgages were required to qualify under two restrictions: (1) GDS $\leq$ 39% and (2) TDS $\leq$ 44%, with mortgage payments calculated using the negotiated contract rates.[7] There were no such restrictions on uninsured mortgages. Following the introduction of the stress tests, mortgages were required to satisfy these debt-servicing ratio restrictions with hypothetical mortgage payments calculated using the qualifying rate.

The qualifying rates are typically much higher than the negotiated contract rates. For example, when STI2 came into effect, the qualifying rate was 4.64%, while the average contract rate for 5-year fixed-rate mortgages was only 2.72%.[8] Hence, the maximum loan amount for which a borrower can qualify under the stress test is much smaller. The Big 6's mortgage credit demand from the borrowers and exposure to

[7]Prior to the stress tests, lenders were more conservative in qualifying variable-rate mortgages. Although not mandatory, lenders might require calculating the GDS/TDS using the greater of the contract rate and the 3-year fixed rate (either posted or discounted).

[8]For more details, see the *Annual State of the Residential Mortgage Market in Canada* published by the Mortgage Professionals Canada in December 2016.

mortgage default risks are greatly affected by the qualifying rate.

4.4 Data

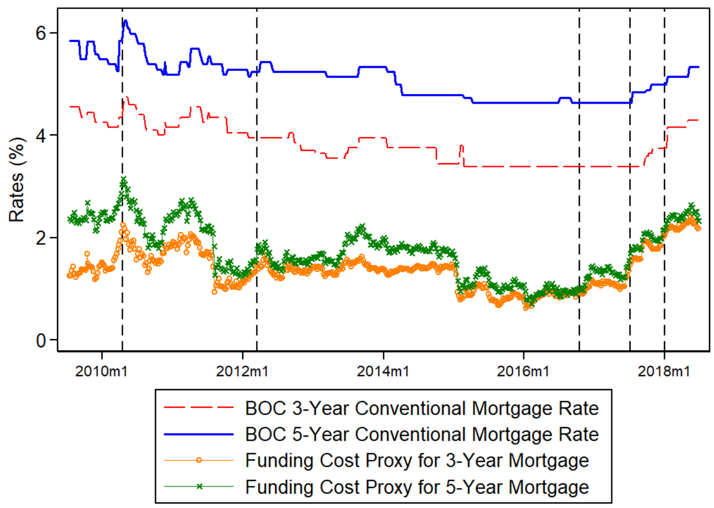
For the purpose of our empirical analysis, we collected posted rate data from CANNEX Financial Exchanges. Our sample includes each of the Big 6's posted rates for 3-year and 5-year fixed-rate mortgages every Wednesday from January 2009 to June 2018. In addition, we obtained the *conventional* 3- and 5-year mortgage rates from the Bank of Canada over the same period, also published every Wednesday. The conventional (or benchmark) rate is the rate *typically* available from the Big 6. It is calculated as the mode of their posted rates.[9] Finally, we collected information on the swap-adjusted 2-year and 4-year bond rates from Bloomberg to serve as cost proxies for 3-year and 5-year mortgages, respectively. The swap-adjusted bond rate is the bond rate plus an interest rate swap spread that is required to change fixed cashflows to floating.[10]

[9]Should there be no mode, the conventional rate is the rate closest to the Big 6 mean. Should there be more than one mode, the conventional rate is the mode closest to the Big 6 mean. Should two modes be equidistant from the Big 6 mean, the mode composed of rates from the banks with the greater value of assets is used as the conventional rate.

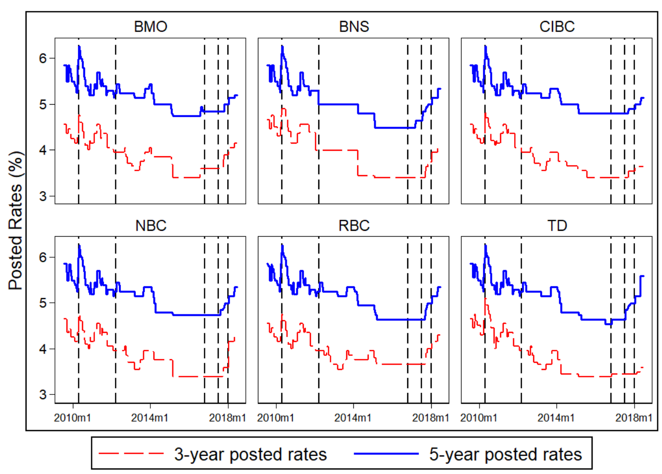
[10]Banks use interest rate swaps to match the maturities of their deposit liabilities and mortgage assets. See Allen and McVanel (2009) for further details. We have also tried other cost proxies such as the 3-year and 5-year government bond rates; the results are unaffected. Data are available through Bloomberg as well.

Figure 4.1: Evolution of Mortgage Rates

(a) Conventional Mortgage Rates and Funding Cost Proxies



(b) Big 6 Posted Rates



From left to right, the vertical dash lines indicate the start of STI1 (04/10), the proposal of STU1 (03/12), the start of STI2 (10/16), the proposal of STU2 (07/17), and the official start of STU2 (01/18). The Big 6 includes Bank of Montreal (BMO), Bank of Nova Scotia (BNS), Canadian Imperial Bank of Commerce (CIBC), National Bank of Canada (NBC), Royal Bank of Canada (RBC), and Toronto-Dominion Bank (TD).

Figure 4.1a displays the evolution of the 3-year and 5-year conventional rates along with their funding cost proxies. When studying STI1 and STU1 we use data from July 2009 to December 2012. For STI2 and STU2 we restrict attention to a subsample of the data covering January 2016 to June 2018. From the figure it can be seen that banks respond to changes in their funding costs by adjusting their posted rates. The figure also displays the dates of the policy changes and in our empirical analysis below we will investigate the differences in the reaction of the 5-year and 3-year rates to their respective funding cost changes.

Figure 4.1b shows rates at each of the Big 6. Table 4.2 shows the summary statistics for the Big 6's posted rates and the swap-adjusted bond rates in these two subsamples. Panel A covers July 2009 – December 2012, while Panel B covers January 2016 – June 2018. In each panel the first two rows report summary statistics for the 3- and 5-year posted rates for each of the Big 6 lenders. The next two rows display the Bank of Canada conventional rates. Note that the means of the posted rates look very similar to the conventional rates. Finally, the last two rows report the swap-adjusted bond rates.

Table 4.3 provides the first evidence of the impact of the two sets of stress tests. As mentioned in the Introduction, and discussed in greater detail below, we expect the 5-year model rate to fall relative to the 3-year model rate following the second set of stress tests, and we expect it to increase following the first. This is exactly what we observe in the data. In the next section we elaborate on our empirical methodology and control for changes in funding costs changes which may also have affected rates at the same time.

Table 4.2: Summary Statistics

Panel A: July 2009 – December 2012					
Variables	Obs	Mean	SD	Min	Max
Big 6 lenders' 3-year posted rates	1080	4.24	0.275	3.65	5.10
Big 6 lenders' 5-year posted rates	1080	5.44	0.264	4.99	6.25
Conventional 3-year mortgage rate	180	4.20	0.245	3.70	4.75
Conventional 5-year mortgage rate	180	5.45	0.254	5.14	6.25
Swap-adjusted 2-year bond rate	180	1.50	0.289	0.94	2.24
Swap-adjusted 4-year bond rate	180	2.04	0.492	1.24	3.16

Panel B: January 2016 – June 2018					
Variables	Obs	Mean	SD	Min	Max
Big 6 lenders' 3-year posted rates	780	3.58	0.247	3.39	4.30
Big 6 lenders' 5-year posted rates	780	4.82	0.226	4.49	5.59
Conventional 3-year mortgage rate	130	3.58	0.318	3.39	4.30
Conventional 5-year mortgage rate	130	4.81	0.225	4.64	5.34
Swap-adjusted 2-year bond rate	130	1.38	0.541	0.62	2.39
Swap-adjusted 4-year bond rate	130	1.54	0.582	0.71	2.65

Note: Units are percentage points. Posted rate data is from CANNEX Financial Exchanges. Conventional rate data is from Bank of Canada. Swap-adjusted 2-year and 4-year bond rates are from Bloomberg.

Table 4.3: Average Conventional Mortgage Rates Before and After Rule Changes

	STI1		STU1		STI2 & STU2	
	3-year	5-year	3-year	5-year	3-year	5-year
Before	4.210	5.500	3.980	5.235	3.390	4.680
After	4.645	6.075	3.950	5.400	4.068	5.110
Difference	0.435	0.575	-0.030	0.165	0.678	0.430
Diff-in-diff	0.140		0.195		-0.248	

Note: Units are percentage points. Each before/after period consists of 10 weeks of observations.

4.5 Empirical Analysis

4.5.1 Methodology

To identify the impact of the stress tests on the Big 6's 5-year posted rates, we adopt a difference-in-difference framework. We compare the changes in the posted rates for 5-year contracts before and after the rule change to changes in posted rates for 3-year contracts. The 3-year contracts represent an ideal control group for the second set of stress tests. They are not affected by the policy since the qualifying rate is only a function of the 5-year rates and so the stress tests do not alter the Big 6's incentives when setting their 3-year posted rates. The 3-year posted rate is set in similar fashion to the 5-year rate because they are close substitutes and the negotiation processes are very similar. Moreover, as can be seen in Figure 4.1a, the two rates trend together prior to the implementation of the tests. Formal evidence supporting the pre-treatment parallel trend assumption is provided in Appendix C.1.

For the first set of stress tests, 3-year rates may not be as suitable a control because there is evidence that a few lenders may have been using these rates to determine qualification prior to the implementation of the tests. We recognize this limitation, but argue in Section 4.5.3 below that, if anything, this will lead to an underestimate of the manipulation that occurs.

Since banks set their posted rates in response to funding cost movements, our difference-in-difference specification will need to control for the underlying funding cost trends. We define $s^j_{i,t} = p^j_{i,t} - b_{i,t}$ as the spread between the posted rate and the corresponding swap-adjusted bond rate, where j denotes bank identity, i denotes mortgage term (3 or 5 years), and t denotes time. Given spreads $s^j_{i,t}$ for each bank, we then calculate the mean and the mode of Big 6's spreads for every week. These are the outcome variables of interest, $y_{i,t}$.[11]

The difference-in-difference regression specification is of the following form:

$$y_{i,t} = \alpha_i + \lambda_t + Policy_{i,t} \times \beta + \epsilon_{i,t}, \tag{4.1}$$

where $Policy_{i,t}$ is an indicator variable that equals 1 for 5-year terms during the treatment period, and β is the coefficient of interest that captures the impact of the policy change on the 5-year outcome variable. α_i is a mortgage-term fixed effect that

[11] Note that this implicitly assumes that the pass-through from funding costs to posted rates is equal to one. Our results are robust to reasonable alternative assumptions on the degree of pass through, but existing estimates for Canada suggest that pass-through is almost complete (see Allen and McVanel (2009)). Alternatively, we could be more flexible and use rates instead of spreads to construct the outcome variables and include funding-cost controls on the right-hand side. The problem with this approach is that, in the context of our difference-in-difference specification, this implies estimating rates of pass-through on short sample periods during which the funding cost does not vary sufficiently.

absorbs the time-invariant determinants of 3-year and 5-year outcome variables. λ_t is a week fixed effect that controls for time-varying shocks common to both 3-year and 5-year outcome variables. One might be concerned about the confounding influence of other policy changes that occurred during our sample periods.[12] However, these other changes influenced the mortgage market as a whole and so the inclusion of the week fixed effects makes separate identification of the impact of the stress tests possible.

4.5.2 The Second Wave of Stress Tests – Longer Term

Timing

Our initial focus is on the second wave of stress tests: STI2 and STU2. We define the periods before and after the policy change as follows:

- Benchmark Period (Before Period): Apr 27, 2016 - Oct 12, 2016 (25 weeks, **Period 0**).
- Treatment Periods (After Periods)
  - Oct 19, 2016 - Apr 5, 2017 (25 weeks, **Period 1**), STI2 in effect.
  - Jul 12, 2017 - Dec 27, 2017 (25 weeks, **Period 2**), STI2 in effect, STU2 expected.

[12] Examples include shorter amortization period and and lower refinancing amount. These policy changes mainly targeted the insured mortgages. On January 17, 2011, Department of Finance announced measures to reduce the maximum amortization period from 35 years to 30 years and lower the limit on refinancing from 90% to 85% of the house value. On June 21, 2012, Department of Finance further decreased the maximum amortization period to 25 years and lowered the refinancing limit to 80% of LTV ratio.

– Jan 3, 2018 - June 20, 2018 (25 weeks, **Period 3**), both STI2 and STU2 in effect.

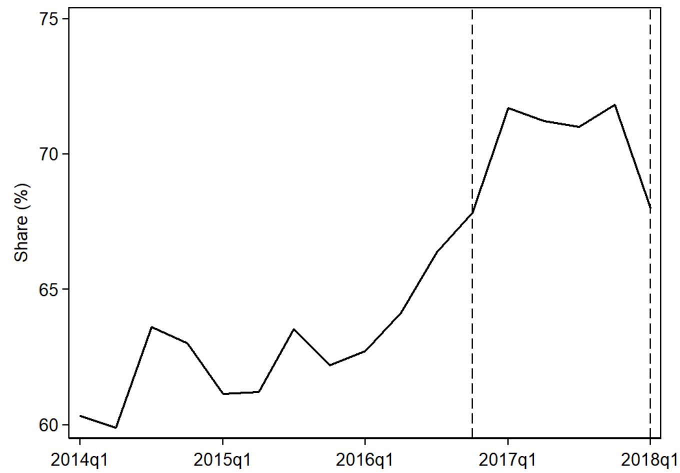
The window-size choices are based on the fact that we only have observations for 25 weeks in periods 2. We have also tried to use different length of the before and after periods. The estimated results are robust to these changes.

In the difference-in-difference regression, Equation 4.1 is estimated three times using observations from periods 0 & 1, periods 0 & 2, and periods 0 & 3, respectively. The estimated β's capture the cumulative treatment effects: impact of STI2 alone, impact of STI2 combined with expected STU2, and impact of STI2 plus STU2, respectively.

The Big 6's Incentives and Hypothesis Development

In period 1, when STI2 came into effect, all insured mortgages were subject to the stress test. Consider a borrower who would have chosen a 5-year insured mortgage had STI2 not been introduced. If she insists on the same choice despite the presence of STI2, the maximum loan for which she could qualify would be smaller. Alternatively, she could substitute towards a 5-year uninsured contract by paying at least 20% down payment. The down payment might either come from unregulated lenders, personal savings, or family and friends. Figure 4.2 shows the substitution pattern from insured to uninsured mortgages. Whether it is because they are borrowing less or switching to other products, the end result is the same: the borrower's demand for *insured* mortgage credit from the the Big 6 shrinks substantially, lowering their profits and increasing the default risks they faced.

Figure 4.2: Uninsured Originations as Percent of Total Value Originated



The quarterly share of uninsured mortgages originated is obtained from Mordel and TeNyenhuis (2018). The vertical dash lines indicate the proposal of STI2 (10/16) and the official start of STU2 (01/18).

We therefore hypothesize that to deal with the problem of shrinking demand and rising default risk the Big 6 had incentive to move the qualifying rate lower and loosen the stress test.[13] This incentive to collectively reduce rates in order to lower the qualification rate is in conflict with the banks' individual incentives to keep rates high in order to more easily engage in price discrimination (Allen et al. (2014b) and Allen et al. (2019)) and also to impose higher prepayment penalties, since these are a function of the posted rate. We hypothesize that this conflicting incentive implies that the mean spread falls, but by less than the mode. We summarize these hypotheses as follows:

Hypothesis 1. *In period 1, with only STI2 in effect, the mean and the mode of*

[13]Note that, due to the underwriting rules, the Big 6 cannot extend the maximum amortization period to make qualification easier.

the Big 6's 5-year spreads should have decreased, but the mode should have fallen by more than the mean.

In period 2, with STI2 in effect and STU2 expected but not yet in place, uninsured 5-year mortgages became less attractive. Even if the borrower managed to sidestep STI2 by substituting to an uninsured mortgage at origination, she would eventually have to face STU2 at the time of refinance or renewal.[14] Therefore, although shrinking demand and rising default risk were still of concern to the Big 6, the problems were less severe than in period 1. Because the banks' individual incentives to set posted rates high conflict with their collective incentive to lower qualifying rate, we expect that the mean spread falls less than the mode.

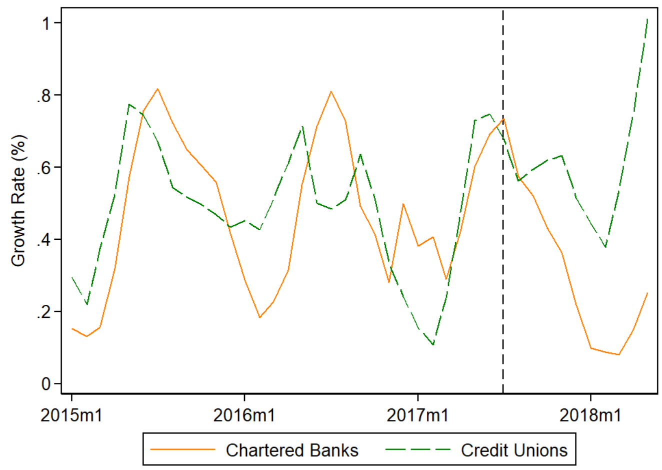
Hypothesis 2. *In period 2, with STI2 in effect and STU2 expected, the mean and the mode of the Big 6's 5-year spreads should have decreased, but in each case by less than in period 1. Moreover, the mode should have fallen by more than the mean.*

In period 3, when both STI2 and STU2 were in effect, the substitution from insured to uninsured 5-year mortgages was no longer a concern to the Big 6. As shown in Figure 4.2, the share of uninsured mortgages dropped substantially right after STU2 came into effect. However, because all of the Big 6's borrowers were subject to the stress tests, a higher qualifying rate would result in an even more significantly negative impact on mortgage credit demand. In addition, some borrowers might even switch to uninsured mortgages provided by federally unregulated lenders, such

[14] Unlike the previous three stress tests, STU2 established stricter rules for qualifying mortgage renewals/refinances. Borrowers with uninsured contracts need to pass the stress test if they wish to transfer their mortgages to another bank. The higher switching costs at renewal made uninsured 5-year contracts less appealing.

as credit unions and mortgage finance companies, to avoid the stress tests. Figure 4.3 shows the substitution pattern from banks to credit unions.

Figure 4.3: Monthly Growth Rate of Outstanding Residential Mortgage Credit



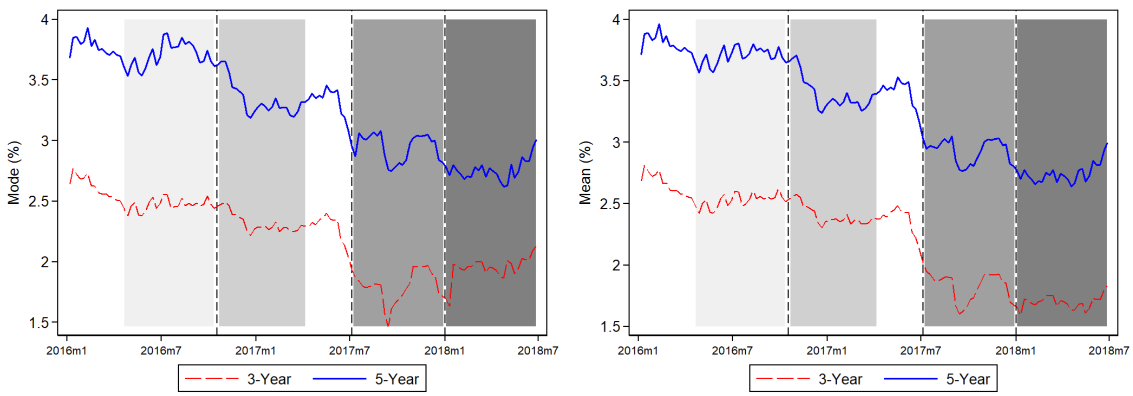
Monthly growth rates are calculated using data from CANSIM table 176-0069 published by Statistics Canada. 3-month centered geometric moving average of the raw monthly growth rates are presented here to get rid of some seasonal noise. The vertical dash line indicates the proposal of STU2 on July 7, 2017.

Therefore, in period 3 the Big 6 had incentive to lower the qualifying rate and further loosen the stress tests to prevent credit demand from further shrinking. The tension between individual and collective incentives in setting the 5-year posted rates again implies that the mean spread falls less than the mode.

Hypothesis 3. *In period 3, under both STI2 and STU2, the mean and the mode of the Big 6's 5-year spreads should have decreased, and by a greater extent than in period 2. Moreover, the mode should have fallen by more than the mean.*

Figure 4.4: Big 6 spreads - Second Wave

(a) Mode (b) Mean



From left to right, the vertical dash lines indicate the start of STI2 (10/16), the proposal of STU2 (07/17), and the official start of STU2 in (01/18). From lightest to darkest, the four shaded areas represents period 0, 1, 2, and 3, respectively.

Results

Figures 4.4a and 4.4b display trends for the outcome variables. They show that the mode and the mean of the 3-year and 5-year spreads followed approximately the same trend in the benchmark period 0. Then in the treatment periods, the gap between 3-year and 5-year mode/mean spreads first narrowed in period 1, widened a bit in period 2, and shrank again in period 3.

Estimation results are presented in Table 4.4, and are consistent with our observations from the graphs. In period 1, the mean and the mode of the 5-year spreads dropped by 18.5 bps and 21.4 bps, respectively. In period 2, the estimated treatment effects on the mean and mode were -7.2 bps and -8.9 bps, respectively. In period 3, these were -13.1 bps and -42.8 bps, respectively.

Table 4.4: Estimated Treatment Effects: STI2 and STU2

	Period 1		Period 2		Period 3	
	STI2 On		STI2 On, STU2 Expected		STI2 & STU2 On	
	Mean	Mode	Mean	Mode	Mean	Mode
$Policy_{i,t}$	-0.185***	-0.214***	-0.0715***	-0.0882**	-0.131***	-0.428***
	(0.0191)	(0.0274)	(0.0137)	(0.0317)	(0.0162)	(0.0340)
Term FE	Y	Y	Y	Y	Y	Y
Week FE	Y	Y	Y	Y	Y	Y
Obs	100	100	100	100	100	100
Adj R^2	0.997	0.994	0.999	0.994	0.998	0.992

Note: Dependent variable is mean/mode of spreads. $Policy_{i,t}$ is an indicator variable that equals 1 for 5-year terms during the treatment period. Units are percentage points. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. All post periods (1,2,3) are 25 weeks after the rule changes, and are compared with the 25-week pre-treatment Period 0. From Jan 2016 to Jun 2018, the average 5-year spread was 3.28 percentage points.

The mean and the mode of the 5-year spreads decreased relative to the 3-year control in each treatment period. The estimated treatment effect in period 2 was smaller than those in period 1 and 3. Furthermore, the treatment effects on the mode were larger than those on the mean (statistically significant in period 3). Together these findings provide supporting evidence for Hypothesis 1, Hypothesis 2, and Hypothesis 3.

Discussion: Rate Coordination

In order to better understand how the Big 6 coordinated to change the qualifying rate, this subsection examines the rate changing episodes in more detail. There were five changes in qualifying rate during the treatment period. In each case the Big 6 managed to control the increase in qualifying rate in response to the surging funding cost trend.

1. 4.64% to 4.84% on July 19, 2017: observing BMO's longstanding rate of 4.84%, TD increased its rate from 4.64% to 4.84% on July 19, making 4.84% the new mode. BNS and NBC followed within 3 weeks.

2. 4.84% to 4.89% on September 27, 2017: TD initiated the change on Aug 30, followed by CIBC (September 13), RBC (September 27), and NBC (October 4).

3. 4.89% to 4.99% on October 25, 2017: RBC initiated the change on October 18, followed by TD, BMO, BNS, and NBC within 2 weeks.

4. 4.99% to 5.14% on January 17, 2018: RBC initiated the change on January 11, followed by TD, BMO, BNS, and NBC within 1 week.

5. 5.14% to 5.34% on May 9, 2018: TD made a change from 5.14% to 5.59% on April 25 but no one followed. RBC initiated the change from 5.14% to 5.34% on April 27, followed by NBC and BNS within 1 week.

Rate changes were infrequent, and we do not have exact information on how posted rates affect banks' profits. Therefore, it is not possible to build a model of rate coordination that can be tested using the available information. However, we do observe three interesting patterns that provide some insight into how banks coordinated a new qualifying rate:

i. Each qualifying-rate change was led either by RBC or TD. These increases were followed shortly afterwards by the other banks to form a new mode. Importantly, the other four banks did not challenge the leader by setting an even higher rate. This "lead-and-follow" coordination pattern suggests that the rate leader was able to increase the qualifying rate in a manageable way.

ii. A tension exists between individual and collective incentives. An individual bank has incentive to increase its own posted rate for the purpose of price discrimination and prepayment deterrence, but a rate increase might also trigger imitation from the other banks due to the "lead-and-follow" coordination pattern, and hence result in a higher qualifying rate. TD appears to have always adjusted its posted rate well above the mode in an effort to profit from a "high individual and low qualifying rate." However, when TD was above the mode, RBC would initiate qualifying rate increases to signal a warning that such an advantage would only be short-lived. This signal seemed to deter TD's potential deviation attempts from Oct 18, 2017 to Apr 18, 2018.

iii. In the case of some deviations, punishment was too costly. When TD made a change from 5.14% to 5.59% on Apr 25, 2018. The other banks did not punish this deviation by moving the qualifying rate to 5.59%, because it would have been too costly to do so.

Robustness

In the Appendix C, we test the robustness of our results to different window lengths and different funding-cost proxies. We consider lengths of the before and after periods ranging from 10 to 50 weeks. The results are presented in Table C.4, and they confirm that the estimated treatment effects are robust to the choice of window length. Note that the lengths of periods 1 and 2 are at most 38 weeks (Oct 19, 2016 – Jul 5, 2017) and 25 weeks (Jul 12, 2017 – Dec 27, 2017) respectively.

Table C.2 presents results for estimation using alternative funding-cost proxies. We use Government of Canada benchmark 3- and 5-year bond rates in place of swap-adjusted 2-year and 4-year bond rates. Findings suggest that the results are robust with respect to these changes.

4.5.3 The First Wave of Stress Tests – Short Term

Timing

We define the before and after periods as 40-week periods before and after the 2010 and 2012 policy changes.[15]

The Big 6's Incentives and Hypothesis Development

Following the introduction of STI1, some borrowers who preferred short-term insured mortgages were affected. The maximum loan amount for which they could qualify would drop sharply if they were to stay with their preferred choices and undergo the stress test. However, they could easily sidestep the problem by choosing insured 5-year fixed-rate mortgage instead. Due to the declining interest rate trend, the Big 6 had incentive to set higher 5-year posted rates, drive up the qualifying rate,

[15] We have tried different starting points for each policy change, using either proposal date, announcement date, or effective date. The estimates do not change much. The results are also robust to choice of time window around the policy changes.

and force more borrowers substitute towards 5-year insured mortgages. By doing so, the Big 6 not only raised the price ceiling and potential profit margin for 5-year insured mortgages, but also increased the share of mortgages locked in at relatively high rate for a longer term. This leads to a hypothesis that we will test using the difference-in-difference regression:

Hypothesis 4. *Following the introduction of STI1, the mean and the mode of the Big 6's 5-year spreads increased.*

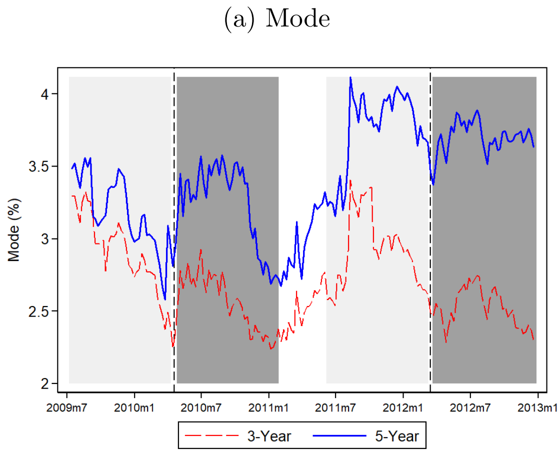
When STU1 was introduced, the Big 6 had similar incentive to set higher 5-year posted rates and qualifying rate.

Hypothesis 5. *Following the introduction of STU1, the mean and the mode of the Big 6's 5-year spreads increased.*

Results

Figures 4.5a and 4.5b display the trends of the outcome variables. They show that, after the introduction of each stress test, the gap between the 3-year and 5-year mean/mode spread widened. Table 4.5 presents the estimated treatment effects for each stress test.

Figure 4.5: Big 6 spreads – First Wave



From left to right, the vertical dash lines indicate the start of STI1 (04/10), the proposal of STU1 (03/12). The light and dark shaded areas represent the before and after periods around each stress test.

As expected, the mean and the mode of the 5-year spreads rose relative to the 3-year control after each of the stress tests, offering supporting evidence for Hypothesis 4 and Hypothesis 5. In response to STI1, the mean and the mode of the 5-year spreads increased by 40 bps and 40.9 bps, respectively. The impact of STU1 on the mean and mode was 32.5 bps and 33.9 bps, respectively. The results are very intuitive when taking into account the Big 6's profit maximization incentive. Under the background of declining mortgage rates from 2008 to 2016, when STI1 or STU1 was in effect, the Big 6 had incentive to adjust higher qualifying rates by increasing their 5-year posted rates. By doing so, the price ceiling of 5-year mortgages increased and more borrowers were forced to substitute from short-term mortgages to 5-year fixed-rate contracts. The Big 6 profited from having more borrowers locked in at a relatively high interest rate for a longer term. The 2009 and 2010 annual reports published by the Canadian Association of Accredited Mortgage Professionals (CAAMP) provide some evidence of such substitution behavior: the share of 5-year mortgages increased from 50% in 2009 to 57% in 2010.

Table 4.5: Estimated Treatment Effects: STI1 and STU1

	STI1 On		STU1 On	
	Mean	Mode	Mean	Mode
$Policy_{i,t}$	0.400***	0.409***	0.325***	0.339***
	(0.0390)	(0.0451)	(0.0512)	(0.0527)
Term FE	Y	Y	Y	Y
Week FE	Y	Y	Y	Y
Obs	160	160	160	160
Adj R^2	0.938	0.927	0.956	0.957

Note: Dependent variable is mean/mode of spreads. $Policy_{i,t}$ is an indicator variable that equals 1 for 5-year terms during the treatment period. Units are percentage points. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. 40-week before and after periods are used for STI1 (Apr 19, 2010) and STU1 (Mar 19, 2012). From Jul 2009 to Dec 2012, the average 5-year spread was 3.4 percentage points.

It should be mentioned that there is anecdotal evidence that prior to STI1 and STU1 a few lenders might have been using their 3-year posted rates to qualify certain mortgage products (e.g. insured variable-rate mortgages). One could be concerned that the Big 6 would also change the way they set their 3-year posted rates after the stress tests. If this were the case, however, it is reasonable to believe that banks would have had incentive to adjust the 3-year posted rate upwards once they were no longer constrained by its qualification role. Therefore, if there were any biases, our estimated treatment effects would understate the Big 6's manipulation of their 5-year posted rates.

Robustness

In Appendix C, we test the robustness of our results to different funding cost proxies, different window lengths, and different policy starting dates. The results are presented in Tables C.3, C.5, and C.6, and they show that the estimated treatment effects are robust with respect to these different specifications.

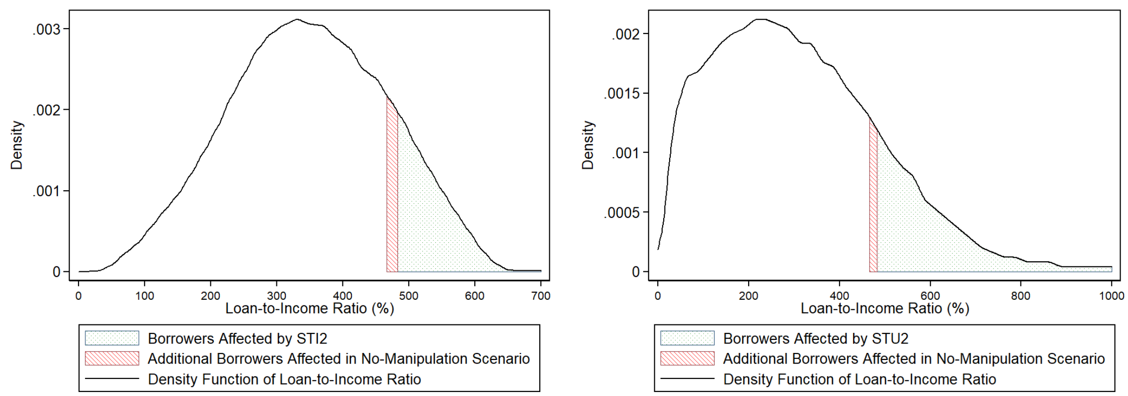
4.6 Impact of Manipulation

In this section we use the estimates obtained in the previous section to provide some insight into what would have happened to the decline in mortgage originations had the Big 6 banks *not* manipulated the qualifying rate after STI2 and STU2. To do so, we focus on mortgages originated prior to the implementation of the stress tests, and investigate how many of these contracts would fail the stress tests under different qualifying rates.

Specifically, we use the loan-to-income ratio (LTI) distribution to back out the GDS distribution assuming a specific qualifying rate, and then calculate the share of mortgages failing the stress tests (i.e. those with GDS $>$ 39%). This share varies with the qualifying rate, and a back-of-the-envelope calculation shows how many more prospective borrowers would have failed the stress tests had the qualifying rate not been manipulated.

Figure 4.6: Share of Borrowers affected by STI2 and STU2

(a) STI2 (b) STU2



We obtained the LTI distribution for insured mortgages originated for a period before STI2 (2015Q4 – 2016Q3) from the *Financial System Review* published by the Bank of Canada in December 2016. The LTI distribution for uninsured mortgages originated for a period before STU2 (2017Q2) is from Bilyk and teNyenhuis (2018). In order to back out the GDS distribution, we make two quite reasonable simplifying assumptions: (i) every mortgage amortizes in 25 years, and (ii) each borrower's other housing expenses (e.g. property tax and heating cost) equals to 1% of the mortgage loan size. Then, for each LTI, given a specific qualifying rate, we can calculate the mortgage payment to income ratio, and hence the GDS. Consider an example where a borrower has gross income Y and $LTI = 600\%$ (i.e. the loan size is $6Y$). After STI2 and STU2 came into effect, the qualifying rate faced by most borrowers was 5.14%. Taking this to be the qualifying rate, the hypothetical annual mortgage payment would be $0.425Y$. Because other housing expenses are assumed to be $6Y \times 1\%$, GDS

$= (0.425Y + 0.06Y)/Y = 48.5\%$. This borrower would fail the stress test.

Figures 4.6a and 4.6b show, respectively, that 14.4% of the insured mortgages and 16.9% of the uninsured mortgages would have failed the stress tests. Using our estimates from the previous section, it can be shown that, had the Big 6 banks not manipulated their 5-year posted rates, the estimated qualifying rate would have instead been $5.14\% + 0.43\% = 5.57\%$. Figures 4.6a and 4.6b show, respectively, that at this higher qualifying rate, 18% of insured mortgages and 19% of uninsured mortgages would have failed the stress tests. Therefore, the policy impact on insured borrower qualification would have been 25% stronger had there been no manipulation, and the impact would have been 12.4% stronger in the uninsured sector.

4.7 Conclusion

This chapter documents the Big 6's strategic response to the introduction of the four stress tests in Canada. The stress tests were intended to tighten rules for mortgage qualification through the debt-to-income constraint. The stringency of the tests depends crucially on the qualifying interest rate, which is tied to the mode of the Big 6's 5-year posted rates. As a result, the Big 6 had incentive to adjust their rates for the purpose of profit maximization.

We present two sets of results. When the first two stress tests came into force, only short-term mortgages were affected. The Big 6 strategically coordinated to keep the qualifying rate relatively high despite the declining funding cost trend. By doing so, more borrowers had to substitute from short-term mortgages to 5-year fixed-rate contracts, and the Big 6 benefited from having more borrowers locked in at a relatively high interest rate for a longer term. When the last two stress tests came into effect, all mortgages originated by the Big 6 were covered, but unlike with the previous result, the Big 6 restrained the qualifying rate from rising in accordance with the surging funding cost to deal with the shrinking mortgage credit demand that resulted from tighter mortgage eligibility criteria.

In addition, we also document some substitution behavior of the borrowers to sidestep the stress tests. For example, some borrowers substituted from insured to uninsured 5-year mortgages to avoid STI2, and some substituted from banks to credit unions to avoid STU2. Such substitution patterns were part of the reasons behind the Big 6's rate posting strategies. Our results suggest that, in order to achieve the preferred target, macroprudential policy maker should take into account the responses from both the credit demand and supply side as well as their interactions.

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Appendix A

Sample Mortgage Renewal Letter

Date: **October 4, 2019**
Your mortgage number:
Property address:

Questions about your Mortga
Renewal Agreement?
Call us at
Visit our website at

Your mortgage is up for renewal on November 10, 2019

Thank you for choosing for your mortgage. Your current mortgage term is coming to an end soon and it's time for you to select a renewal term. This Mortgage Renewal Agreement contains our current posted interest rates for the terms we offer but we have special offers available if you contact us.

Call your branch today to set up an appointment to renew your mortgage and receive expert advice and competitive rates. If you prefer, you can renew by calling

We are pleased to help you find the mortgage solution that best meets your specific needs.

P.S. Be sure to call us to renew your mortgage before the renewal date to avoid your mortgage being automatically renewed into a 6 month fixed rate closed term.

Page 2

Your current mortgage details

Maturity Date / New Term Start Date	....	Nov 10, 2019
Your mortgage term and prepayment type	....	5 Year Closed
Interest Rate	....	2.8900%
Rate Type	....	Fixed
Payment Frequency	....	Bi-Weekly
Principal and Interest Payment	....	
Property Tax	....	
Your Total Payment[4]	....	
Estimated Principal Balance at Maturity Date[1]	....	
Mortgage Protection Premium	....	Uninsured
Time remaining to payoff your mortgage (Amortization period)	....	21 years, 7 months

[1] Accrued interest from the last regular payment date to the maturity date would be due if you paid your mortgage in full on the maturity date.

The renewal options outlined in this Mortgage Renewal Agreement are based on your existing payment frequency and assuming all payments that are due up to and including the maturity date are paid as scheduled.

1 - Please indicate which term and mortgage solution option you are accepting by signing your initial in the appropriate area indicated and return your signed Mortgage Renewal Agreement to your branch.

Your New Term Start Date will begin on the current maturity date. Based on your preference selected below, interest will be calculated and charged from this date on and your new term will end on the New Maturity Date.

Fixed Interest Rate Renewal Options

New Term	New Maturity Date	Annual Interest Rate[2] / APR[3]	New Principal and Interest Payment	Property Tax	New Total Bi-Weekly Payment[4]	Total P & I Payments over the Term	Total cost of borrowing over the Term	Initial your choice here
6 Month Flexible[11]	May 10, 2020	4.7500%						
1 Year Closed	Nov 10, 2020	3.6400%						
2 Year Closed	Nov 10, 2021	3.7400%						
3 Year Closed	Nov 10, 2022	4.3900%						
4 Year Closed	Nov 10, 2023	4.5900%						
5 Year Closed	Nov 10, 2024	5.1900%						
7 Year Closed	Nov 10, 2026	5.6900%						
10 Year Closed	Nov 10, 2029	6.1900%						
6 Month Open[11]	May 10, 2020	7.2500%						
1 Year Open[11]	Nov 10, 2020	7.2500%						

Appendix B

Likelihood Function

Consider three different types of borrowers and the respective likelihood functions: (1) switching borrowers, (2) loyal borrowers obtaining multiple quotes, and (3) loyal borrowers accepting the home banks' free initial quote. The likelihood function depends on borrowers' search probabilities, $Pr(n_i = l)$, as set out in equation (3.10). For simplicity of exposition, assume in equilibrium that the optimal initial offer is high enough, such that the borrower searches l banks with positive probability, $\forall\, l = 2, 3, \cdots, N$.

Case 1: Switching Borrowers

Let B_i denote the winning bank, and P_i denote the winning price. The probability of observing a borrower switching to a rival provider j and paying a price lower than

p is:

$$
\begin{aligned}
&Pr(P_i \leq p, B_i = j, B_i \neq h)\\
&= \sum_{l=2}^{N} Pr(n_i = l) Pr(P_i \leq p, B_i = j, B_i \neq h | n_i = l)\\
&= \sum_{l=2}^{N} Pr(n_i = l) Pr(B_i = j, B_i \neq h | n_i = l) Pr(P_i \leq p | n_i = l, B_i = j, B_i \neq h)\\
&= \sum_{l=2}^{N} Pr(n_i = l) \frac{1 - Pr(\omega_h - \lambda \leq \omega_{-h} | n_i = l)}{l-1} \frac{l-1}{N-1} Pr(P_i \leq p | n_i = l, B_i = j, B_i \neq h),
\end{aligned}
$$

where the probability of a borrower paying a price lower than p conditional on that she searches l lenders and switches to lender j is given by:

$$
\begin{aligned}
&Pr(P_i \leq p | n_i = l, B_i = j, B_i \neq h)\\
&= Pr(C - \delta V + \omega_{(2)} \leq p | n_i = l, \omega_{(1)} = \omega_j, j \neq h)\\
&= \int_{-\infty}^{\infty} Pr(\omega_{(2)} \leq p - (c - \delta V) | n_i = l, \omega_{(1)} = \omega_j, j \neq h) dF(c)\\
&= \int_{-\infty}^{\infty} \left\{ \left(1 - \frac{1}{Pr_{j|n_i=l}}\right) G_{(1)|n_i=l}(p - c + \delta V) + \left(\frac{1}{Pr_{j|n_i=l}}\right) G_{-j|n_i=l}(p - c + \delta V) \right\} dF(c).
\end{aligned}
$$

$Pr_{j|n_i=l} \equiv Pr(\omega_j \leq \omega_{-j} | n_i = l)$ is the probability that bank j wins the auction conditional on j being in the l-bank choice set, where $\omega_{-j} \equiv \min\{\min_{k \in n_i \setminus \{j,h\}}\{\omega_k\}, \omega_h - \lambda\}$. Recall that $\omega^t_{(k)}$ denotes the k^{th} order statistic among $(\omega_{h^t} - \lambda, \omega_1, \omega_2, \cdots, \omega_{n_i - 1})$. $G_{(1)|n_i=l}$ and $G_{-j|n_i=l}$ are the CDFs of $\omega_{(1)}$ and ω_{-j}, respectively. The last equation follows from the property of the T1EV distributed idiosyncratic cost shocks. See Brannman and Froeb (2000) for a more detailed discussion.

The first order derivative of $Pr(P_i \leq p, B_i = j, B_i \neq h)$ with respect to p yields the likelihood contribution of a switching borrower i:

$$
\begin{aligned}
&l_i(p, B_i = j, B_i \neq h) \\
&= \sum_{l=2}^{N} Pr(n_i = l) \frac{1 - Pr_{h|n_i=l}}{N-1} \\
&\quad \times \int_{-\infty}^{\infty} \left\{ \left(1 - \frac{1}{Pr_{j|n_i=l}}\right) g_{(1)|n_i=l}(p - c + \delta V) + \left(\frac{1}{Pr_{j|n_i=l}}\right) g_{-j|n_i=l}(p - c + \delta V) \right\} dF(c).
\end{aligned}
$$

Case 2: Loyal Borrowers Holding Auctions

The probability of observing a borrower who obtains multiple quotes but chooses to stay with her home bank and pays a price lower than p is

$$
\begin{aligned}
&Pr(P_i \leq p, B_i = h, n_i > 1) \\
&= \sum_{l=2}^{N} Pr(n_i = l) Pr(P_i \leq p, B_i = h | n_i = l) \\
&= \sum_{l=2}^{N} Pr(n_i = l) Pr(B_i = h | n_i = l) Pr(P_i \leq p | n_i = l, B_i = h),
\end{aligned}
$$

and the corresponding likelihood contribution is

$$
\begin{aligned}
&l_i(p, B_i = h, n_i > 1) \\
&= \sum_{l=2}^{N} Pr(n_i = l) Pr_{h|n_i=l} \\
&\quad \times \int_{-\infty}^{\infty} \left\{ \left(1 - \frac{1}{Pr_{h|n_i=l}}\right) g_{(1)|n_i=l}(p - c + \delta V) + \left(\frac{1}{Pr_{h|n_i=l}}\right) g_{-h|n_i=l}(p - c + \delta V) \right\} dF(c).
\end{aligned}
$$

Case 3: Loyal Borrowers Accepting Initial Quotes

The probability of observing a borrower who accepts her home bank's free initial quote and pays a price lower than p is

$$\begin{aligned}
&Pr(P_i \leq p, B_i = h, n_i = 1) \\
&= Pr(n_i = 1)Pr(P_i \leq p|n_i = 1) \\
&= (1 - H(\bar{\kappa}_2^*))Pr(\bar{\kappa}_2^* + \lambda + C - \delta V + E[\omega_{(2)}^t|n^t = 2] \leq p) \\
&= (1 - H(\bar{\kappa}_2^*))F(p - (\bar{\kappa}_2^* + \lambda - \delta V + E[\omega_{(2)}^t|n^t = 2])),
\end{aligned}$$

and the corresponding likelihood contribution is

$$\begin{aligned}
&l_i(p, B_i = h, n_i = 1) \\
&= (1 - H(\bar{\kappa}_2^*))f(p - (\bar{\kappa}_2^* + \lambda - \delta V + E[\omega_{(2)}^t|n^t = 2])).
\end{aligned}$$

Likelihood function

Conditional on the home-bank identity h and the winning bank identity b, the borrower's likelihood contribution is given by:

$$
l_i(p,b,h) = \begin{cases}
\sum_{l=2}^{N} Pr(n_i = l) \frac{1 - Pr_{h|n_i=l}}{N-1} & \\
\times \int_{-\infty}^{\infty} \Big\{ \left(1 - \frac{1}{Pr_{b|n_i=l}}\right) g_{(1)|n_i=l}(p - c + \delta V) & b \neq h, \\
\qquad + \left(\frac{1}{Pr_{b|n_i=l}}\right) g_{-b|n_i=l}(p - c + \delta V) \Big\} dF(c) & \\
 & \\
\sum_{l=2}^{N} Pr(n_i = l) Pr_{h|n_i=l} & \\
\times \int_{-\infty}^{\infty} \Big\{ \left(1 - \frac{1}{Pr_{h|n_i=l}}\right) g_{(1)|n_i=l}(p - c + \delta V) & b = h. \\
\qquad + \left(\frac{1}{Pr_{h|n_i=l}}\right) g_{-h|n_i=l}(p - c + \delta V) \Big\} dF(c) & \\
+ (1 - H(\bar{\kappa}_2^*)) f(p - (\bar{\kappa}_2^* + \lambda - \delta V + E[\omega_{(2)}^t | n^t = 2])) &
\end{cases}
$$

Appendix C

Robustness Check

C.1 Test of Parallel Pre-Treatment Trends Assumption

Consider the following difference-in-difference regression specification:

$$
\begin{aligned}
y_{i,t} = & \alpha_i + \lambda_t + Policy_{i,t}^{m=-3} \times \beta_{-3} + Policy_{i,t}^{m=-2} \times \beta_{-2} \\
& + Policy_{i,t}^{m=+1} \times \beta_{+1} + Policy_{i,t}^{m=+2} \times \beta_{+2} + Policy_{i,t}^{m=+3} \times \beta_{+3} + \epsilon_{i,t},
\end{aligned}
$$

where m represents a 2-month period. $Policy_{i,t}^{m=-h}$ is an indicator variable that equals 1 for 5-year terms within $2h$ to $2(h-1)$ months before the policy change. $Policy_{i,t}^{m=h}$ is an indicator variable that equals 1 for 5-year terms within $2(h-1)$ to $2h$ months after the policy change. For example, $Policy_{5,t}^{m=-2} = 1$ when t lies in between the 4 months to 2 months interval prior to the policy change.

Note that $Policy_{i,t}^{m=-1}$ is not included in the regression, because we set the 2-month period right before the policy change as our baseline period. The estimated treatment effects in other periods' β's are interpreted as the differences relative to the baseline period. The parallel pre-treatment trends assumption implies that $\beta_h = 0, \forall h < 0$.

Table C.1 presents the estimated treatment effects and provides evidence supporting the assumption of parallel pre-treatment trends.

Table C.1: Test of Parallel Pre-Treatment Trends Assumption

Policy Change	STI1: Apr 19, 2010		STU1: Mar 19, 2012		STI2: Oct 17, 2016	
Outcome	Mean	Mode	Mean	Mode	Mean	Mode
$Policy_{i,t}^{m=-3}$	-0.0489	-0.0287	-0.250**	-0.172	0.00997	-0.0442
	(0.0843)	(0.100)	(0.0828)	(0.0874)	(0.0203)	(0.0372)
$Policy_{i,t}^{m=-2}$	-0.112	-0.119	-0.0412	0.000500	0.0335	0.0814
	(0.0813)	(0.0970)	(0.0384)	(0.0318)	(0.0175)	(0.0423)
$Policy_{i,t}^{m=+1}$	0.202*	0.229*	0.0583	0.124	-0.107**	-0.134**
	(0.0832)	(0.100)	(0.0707)	(0.0773)	(0.0366)	(0.0491)
$Policy_{i,t}^{m=+2}$	0.258**	0.305**	0.0869	0.138*	-0.214***	-0.243***
	(0.0836)	(0.0995)	(0.0440)	(0.0524)	(0.0203)	(0.0372)
$Policy_{i,t}^{m=+3}$	0.436***	0.483***	0.0457	0.0592	-0.199***	-0.237***
	(0.0836)	(0.0995)	(0.0317)	(0.0321)	(0.0225)	(0.0386)
Term FE	Y	Y	Y	Y	Y	Y
Week FE	Y	Y	Y	Y	Y	Y
Obs	96	96	96	96	96	96
Adj R^2	0.969	0.968	0.987	0.985	0.998	0.997

Note: Dependent variable is mean/mode of spreads. Units are percentage points. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Parallel pre-treatment trends assumption implies that the coefficient on $Policy_{i,t}^{m=h}, \forall h < 0$ equals 0.

C.2 Alternative Funding Cost Proxies

Table C.2: Estimated Treatment Effects with Alternative Funding Cost Proxies: STI2 and STU2

	Period 1		Period 2		Period 3	
	STI2 On		STI2 On, STU2 Expected		STI2 & STU2 On	
	Mean	Mode	Mean	Mode	Mean	Mode
$Policy_{i,t}$	-0.139***	-0.168***	-0.0169	-0.0336	-0.0139	-0.310***
	(0.0183)	(0.0254)	(0.0157)	(0.0286)	(0.0188)	(0.0311)
Term FE	Y	Y	Y	Y	Y	Y
Week FE	Y	Y	Y	Y	Y	Y
Obs	100	100	100	100	100	100
Adj R^2	0.997	0.995	0.998	0.995	0.998	0.993

Note: Use Government of Canada benchmark 3-year and 5-year bond rates as funding cost proxies. Dependent variable is mean/mode of spreads. Units are percentage points. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. All post periods (1,2,3) are 25 weeks after the rule changes, and are compared with the 25-week pre-treatment Period 0.

Table C.3: Estimated Treatment Effects with Alternative Funding Cost Proxies: STI1 and STU1

	STI1: Apr 19, 2010		STU1: Mar 19, 2012	
	Mean	Mode	Mean	Mode
$Policy_{i,t}$	0.257***	0.267***	0.389***	0.404***
	(0.0396)	(0.0474)	(0.0460)	(0.0485)
Term FE	Y	Y	Y	Y
Week FE	Y	Y	Y	Y
Obs	160	160	160	160
Adj R^2	0.940	0.925	0.964	0.963

Note: Use Government of Canada benchmark 3-year and 5-year bond rates as funding cost proxies. Dependent variable is mean/mode of spreads. Units are percentage points. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. 40-week before and after periods are used for each policy change.

C.3 Different Time Windows

Table C.4: Estimated Treatment Effects with Different Before and After Periods: STI2 and STU2

	Period 1		Period 2		Period 3	
	STI2 On		STI2 On, STU2 Expected		STI2 & STU2 On	
	Mean	Mode	Mean	Mode	Mean	Mode
	Panel A: 10-week before and after periods					
$Policy_{i,t}$	-0.140**	-0.180**	-0.0668*	-0.0226	-0.150***	-0.413***
	(0.0392)	(0.0505)	(0.0311)	(0.0515)	(0.0292)	(0.0720)
Obs	40	40	40	40	40	40
Adj R^2	0.995	0.992	0.998	0.994	0.998	0.987
	Panel B: 20-week before and after periods					
$Policy_{i,t}$	-0.184***	-0.221***	-0.0797***	-0.0922*	-0.150***	-0.448***
	(0.0226)	(0.0309)	(0.0164)	(0.0365)	(0.0165)	(0.0407)
Obs	80	80	80	80	80	80
Adj R^2	0.996	0.994	0.999	0.994	0.999	0.991
	Panel C: 38-week before and after periods					
$Policy_{i,t}$	-0.167***	-0.185***	—	—	-0.0871***	-0.373***
	(0.0142)	(0.0198)	—	—	(0.0176)	(0.0260)
Obs	152	152	—	—	152	152
Adj R^2	0.997	0.995	—	—	0.997	0.993
	Panel D: 50-week before and after periods					
$Policy_{i,t}$	—	—	—	—	-0.0513**	-0.306***
	—	—	—	—	(0.0189)	(0.0270)
Obs	—	—	—	—	200	200
Adj R^2	—	—	—	—	0.996	0.990

Note: Dependent variable is mean/mode of spreads. Units are percentage points. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. All models include loan-term dummy and week dummy variables.

Table C.5: Estimated Treatment Effects with Different Window Length: STI1 and STU1

	STI1: Apr 19, 2010		STU1: Mar 19, 2012	
	Mean	Mode	Mean	Mode
	Panel A: 10-week before and after periods			
$Policy_{i,t}$	0.220**	0.256**	0.0793	0.143*
	(0.0672)	(0.0817)	(0.0614)	(0.0668)
Obs	40	40	40	40
Adj R^2	0.940	0.928	0.987	0.985
	Panel B: 20-week before and after periods			
$Policy_{i,t}$	0.321***	0.360***	0.118**	0.139***
	(0.0451)	(0.0512)	(0.0363)	(0.0367)
Obs	80	80	80	80
Adj R^2	0.944	0.943	0.990	0.990
	Panel C: 30-week before and after periods			
$Policy_{i,t}$	0.418***	0.441***	0.221***	0.230***
	(0.0475)	(0.0477)	(0.0540)	(0.0556)
Obs	120	120	120	120
Adj R^2	0.915	0.931	0.964	0.964
	Panel D: 50-week before and after periods			
$Policy_{i,t}$	0.369***	0.363***	0.400***	0.429***
	(0.0369)	(0.0437)	(0.0470)	(0.0502)
Obs	200	200	200	200
Adj R^2	0.937	0.918	0.954	0.952

Note: Dependent variable is mean/mode of spreads. Units are percentage points. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. All models include loan-term dummy and week dummy variables.

C.4 Alternative Policy Starting Dates

Table C.6: Estimated Treatment Effects with Alternative Policy Starting Dates: STI1 and STU1

	STI1: Feb 16, 2010		STU1: Jun 21, 2012	
	Mean	Mode	Mean	Mode
$Policy_{i,t}$	0.382***	0.408***	0.197***	0.215***
	(0.0503)	(0.0533)	(0.0473)	(0.0522)
Term FE	Y	Y	Y	Y
Week FE	Y	Y	Y	Y
Obs	160	160	160	160
Adj R^2	0.876	0.885	0.967	0.964

Note: Dependent variable is mean/mode of spreads. Units are percentage points. Robust standard errors are in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. 40-week before and after periods are used for each policy change.