Dynamic Competition in Negotiated Price Markets*

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January 27, 2020

Abstract

This paper develops 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 recent Canadian macroprudential policies.

Keywords: mortgages, search costs, switching costs, price negotiation, dynamic competition

*Preliminary and incomplete. The views in this paper are those of the authors and do not represent those of the Bank of Canada. Li is deeply grateful to his supervisor Robert Clark for his invaluable guidance and support, and thanks the Bank of Canada for its hospitality while working on this project. We thank the analysts at TransUnion who graciously answered all of our questions and Vladimir Skavysh for helping to manage our Big data. Helpful comments were provided by Brant Abbott, Christopher Ferrall, Allen Head, Brent Hickman, Jean-François Houde, Beverly Lapham, Jonathan Lee, Yao Luo, James MacKinnon, Oleksandr Shcherbakov, and seminar participants at the 53rd Annual Conference of the Canadian Economics Association, the 2019 Fellowship Learning Exchange at the Bank of Canada, University of Toronto, and the IO working group at Queen's University. Correspondence to: [a]Jason Allen - Bank of Canada, Ottawa, Ontario, K1A 0G9; Email: jallen@bankofcanada.ca, [b]Shaoteng Li - Queen's University, Dunning Hall, 94 University Avenue, Kingston, Ontario, K7L3N6; Email: lis@econ.queensu.ca

1 Introduction

This paper 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 important in negotiated-price markets. Unlike in posted prices markets, where comparison websites for a product might be available, each price quote entails costly search and negotiation. In addition, repeated interactions over time induce switching costs. A switching cost is incurred every time a customer switches providers.[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 should use relatively low prices to attract new customers and poach those of their rivals, and then charge 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 not aware of any quantitative study taking this salient feature into account.

In this paper, 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 mortgage products fixing interest rates for the entire amortization period. The majority of home buyers take out 5-year fixed-rate mortgages. 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.

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

[1] 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.

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. We observe a borrower's mortgage payment history and use it, along with outstanding 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 anonymized borrowers, we 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 5.7 basis points (bps) higher than new borrowers; borrowers who switch banks at renewal on average pay 9.7 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 12.5% of renewers switch mortgage providers.

We build a dynamic model of price negotiation with search and switching costs to explain the observed pricing pattern. We follow Allen et al. (2019) but extend their model in an important way; 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 important 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 differently in policy evaluations, because lenders price these two types of borrowers differently.

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

[2]The home bank for a new borrower is the one that previously provided some other credit product, e.g. credit card. For a renewer, the home bank is the previous period mortgage provider.

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 the chosen 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 additional offers because 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) borrowers' search cost distribution and switching cost, and (2) banks' lending cost distribution and discount factor. We present an identification argument based on a dataset of borrowers' interest cost distribution and switching behaviors. 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. The lenders' discount factor over a 5-year term is estimated to be 0.917, corresponding to an annual interest rate of 1.74%, which is about 100 bps lower than the average contract rate in our sample. Borrowers, on the other hand, have nontrivial search and switching costs. They on average face a per-bank search cost of $655 (that is 2.3% of the average interest cost) and obtain only 2.6 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 $123 (per $100k loan). The number is tripled for renewers; it is much more costly to switch away from a mortgage relationship than a non-mortgage one.

We use the model to conduct counterfactual analyses and 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 more detail in section 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 tests 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, a static merger analysis produces biased results: (i) static merger simulation overestimates the impact of a hypothetical merger,[4] and (ii) retrospective merger evaluation using only purchase contracts underestimates the merger impact on renewals. 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, Hong and Shum (2006) and Giulietti et al. (2014) for retail electricity. The goal is to use search costs to explain the observed price dispersion, identify the search cost distribution, and quantify its welfare implications. A typical assumption is that firms have common costs in servicing every consumer and play mixed pricing strategies. Consumers are assumed to have perfect knowledge about the price distribution in the market, and decide their search activities trading off the cost of search with the marginal benefit of an extra quote. The equilibrium price distribution is such that firms are indifferent between posting any price in the equilibrium support. Randomness in search costs determines the observed price distribution, which in turn identifies the search cost distribution. In posted-price markets, the common cost assumption seems plausible. However, in markets where prices are negotiated, the final price that a customer pays is individualized to reflect the heterogeneity in firm-specific servicing costs, which might be either observed or 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 prediction 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.

Another challenge for most empirical studies on negotiated-price markets is that researchers often only observe the final price and not all quotes. 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 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).

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. More recently, specific papers include Shum (2004) for the breakfast-cereal market, Kim (2006) for cellular service, Dubé et al. (2009) for packaged foods, Shcherbakov (2016) for the cable television market, Handel (2013) for the health insurance market, and Fleitasl (2016) for the drug insurance market. Some of these focus on dynamic price competition among forward-looking firms, and find that switching costs could promote competition and lead to lower equilibrium prices (c.f. Dubé et al. (2009), Shcherbakov (2016), and Cabral (2016)). Consistent with their findings, in the counterfactual experiment, we show that interest costs are lower with than without switching costs. In banking markets there is also extensive interest in switching costs. See for example Ausubel (1991) for credit cards, Ho (2015) for the bank-deposit market, and Thiel (2018) for the Dutch mortgage market. All of these papers ignore search frictions, and assume that consumers have perfect information about the prices available in the market and choose the best option taking into account switching costs. This assumption is reasonable in posted-price markets but does not fit into a negotiated-price market setting. We cannot simply take the approaches used in posted-price markets to identify the switch frictions in our setting.

In our setting, we only observe the final contract price, therefore, we need to explicitly model how the observed price distributions are generated and how they are affected by search and switching frictions in a tractable way. Firms' pricing strategies, however, 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.

The paper is organized as follows. Section 2 introduces institutional details and the data. Section 3 describes the model primitives and and characterize the equilibrium. Section 4 discusses non-parametric identification of the model. Section 5 specifies our empirical framework. Section 6 presents the estimation results. Section 7 presents our counterfactual experiments. Section 8 concludes.

2 Institutional Details and Data

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 and HSBC Bank Canada), and two mortgage finance companies operating nationally (MCAP and First National). Together these lenders originate more than 85% of the 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.[5]

Posted mortgage rates are set weekly and nationally. Lenders post their mortgage rates across different maturities, and these are common across all local markets.[6] Website aggregators then advertise these rates along with a host of other lender rates and might even provide advice. Non-broker mortgage applications are done at the branch level and not electronically. Broker transactions often happen over the phone. Less than 1% of borrowers pay the standard posted rate.[7] 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. Finally, the majority of insured mortgages are securitized and the collection of securitized mortgages (MBS) is held on-balance sheet as high-quality liquid assets for liquidity purposes (Liquidity Coverage Ratio).

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. The majority of home buyers take out 5-year fixed-rate mortgages (FRM). Hence, every five years they are forced to renew their mortgage and obtain a new interest rate for the outstanding balance.[8] Mortgage markets in many other countries

[5]Brokers intermediate about one-third of mortgages over our sample period. See Allen et al. (2014b) for a detailed analysis of brokers in the Canadian market, and Robles-Garcia (2019) for the UK market.

[6]Every Wednesday the Bank of Canada then constructs a benchmark posted rate, which is used in stress-testing as part of the government's macroprudential policy toolkit.

[7]This is much lower than in Allen et al. (2019). This is largely because lenders now often have two posted prices – their standard posted prices used to calculate prepayment fees and discourage early refinancing, and 'specials'. The 'standard' posted rate represent a price ceiling, because in Canada it is illegal to charge interest rates higher than one's posted rates. Specials tend to be targeted at first-time home-buyers. Therefore, those facing the standard posted rates are mostly renewers.

[8]Banks impose significant penalties for refinancing before the end of the term. Refinancing is uncommon in Canada, unlike in the US. This is mostly because of the relatively short term of the mortgage contract (5 years versus 30), which makes the benefits from refinancing, that might come from lower in-

(e.g. Netherlands, Switzerland, UK) are similar: borrowers periodically renew short-term fixed-rate mortgages over a much longer amortization period.This feature makes studying banks' pricing strategies substantially easier than the U.S. market.[9] Chen et al. (2018), for example, document strong counter-cyclical mortgage refinancing activity associated with equity extraction. The refinancing decision is therefore endogenous. This substantially complicates the search 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 game played by the lenders.[10] 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 then, do renewals work in Canada? A household will typically sign a 5-year FRM. Near the end of the 5-year contract, typically six months prior, the incumbent lender sends the borrower a notice by mail about the upcoming renewal and offers a rate.[11] 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.[12] In addition, unlike in posted-price markets, it is costly for borrowers to

terest rates relative to the large penalties imposed, less attractive compared to simply waiting to renewal.

[9]This feature also 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. With respect to renewal risk, this is largely mitigated by mortgage insurance. Borrowers with a LTV ratio above 80% at origination are mandated to buy mortgage insurance backed by the government. Banks must renew even in the case where insured mortgages go underwater. Mortgages with an 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. With respect to interest rate risk, households are exposed, and aware that they might face a very different rate environment at renewal.

[10]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).)

[11]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.

[12]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 important. According to the Mortgage Consumer Survey conducted by the CMHC in 2017, other than rates, the top reason for not switching is that borrowers value their existing relationship.

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.

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.[13] 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 payment on other debt, physical address up to the forward sortation area (FSA).[14] We also observe some mortgage contract information, including the lender's identity, loan amount, loan term, amortization, funding date, monthly payment,[15] outstanding balance, and an indicator for mortgage insurance.[16] We also use the data to derive variables essential to our empirical study. We use the monthly payment and changes in outstanding balance to calculate the interest rate and effective amortization. We then 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 banks by the pre-mortgage relationships built on other credit products.

In addition to monthly anonymized credit bureau data, we have access to another anonymized contract-level administrative dataset, which offers information on mortgages provided by federally regulated lenders.[17] We match individuals at the loan-account level. This dataset is very similar to that used in Allen et al. (2019).[18] It allows us to

[13]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.

[14]The FSA is the first three digits of a postal code. We observe about 1,500 FSAs in our sample. We can also control for postal code level location, however, the full postal code is encrypted.

[15]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.

[16]Mortgage insurance is mandatory for mortgages with LTV ratios greater than 80%.

[17]This dataset, however, lacks a key piece of information: the identity of renewers' previous mortgage providers. We obtain this information from the credit bureau data.

[18]Allen et al. (2019) focus on newly originated contracts only. Our study requires observing renewers'

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 demographic data at FSA level in 2016 census year to include information such as population and median income level. Finally, we include FSA-level house price data 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 January 2018. 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.[19] 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 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.

2.3 Market Features

In this subsection, we present some descriptive evidence that motivates the development of our structural model. In Section 3, we build a model that captures and explains these salient market features. Table 1 presents the summary statistics of borrowers' characteristics and contract information. Table 2 shows a summary of the mortgage rates by different types of borrowers. Table 3 reports the regression results that describe the correlations between negotiated contract rates and borrower characteristics.

In what follows, we present four key features that characterize the pricing pattern and shopping behavior in the Canadian mortgage market. Similar features are also shared by

contract information, and importantly their previous lender and switching behaviors.

[19]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 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.

Feature 2: 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 2.75 lenders. The average number of quotes reported in Allen et al. (2014b) was under 3. Table 1, however, suggests that the average number of available lenders in local markets is close to 7.[20]

Feature 3: Renewers rarely switch even though switchers tend to have better interest rates. Table 2 shows that only about 12.5% of renewers switched to rival banks. This is despite the fact that switchers, on average, receive a discount relative to non-switchers of 11 bps.

Feature 4: "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 2, as well as the regression estimates in Table 3.

[20] 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.

Table 1: Summary Statistics

	mean	sd	p25	p50	p75
	Panel A: New Borrowers				
Interest Rate	2.75	0.28	2.59	2.69	2.9
Loan size	255.19	123.06	165.76	235.175	323.855
Loan limit	255.19	123.06	165.76	235.175	323.855
Credit	755.17	49.20	723	759	792
Age	36.12	10.62	28	33	42
Bond rate	1.03	0.37	.73	.93	1.44
Amortization	24.12	1.70	22	25	25
# lender	6.58	1.82	6	7	8
FSA income	77.54	22.42	61.76	73.1	89.87
	Panel B: Renewers				
Interest Rate	2.81	0.36	2.6	2.7	2.99
Loan size	198.41	92.47	132.82	182.79	249.01
Loan limit	225.65	104.41	150.91	209.865	284.57
Credit	776.88	76.34	729	788	838
Age	45.73	12.04	36	44	54
Bond rate	1.07	0.38	.74	.94	1.51
Amortization	22.36	4.45	19	21	25
# lender	6.82	1.84	6	7	8
FSA income	77.89	22.66	61.7	73.79	90.99

Note: Number of observations is 13,662: 6,808 are new, and 6,854 are renewers. Units for loan size, loan limit, and income are $1,000; units for Interest Rate and Bond Rate are percentage points, and units for amortization and age are years. Loan size refers to the current balance of the mortgage contract, while loan limit is the initial loan amount at origination. 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.

Table 2: Summary Statistics: Interest Rates

Purpose	mean	sd	p25	p50	p75	obs
Purchase (%)	2.75	0.28	2.59	2.69	2.9	6,808
Renewal (%)	2.82	0.37	2.6	2.74	2.99	6,000
Switch (%)	2.71	0.29	2.5	2.64	2.87	854

Table 3: Regression Results

	Interest Rate (bps)	
Loan size	-0.0278***	(0.00224)
Credit	-0.0417***	(0.00405)
Bond rate	0.153***	(0.0152)
# lender	-0.695***	(0.153)
Amortization	0.223**	(0.0785)
FSA income	-0.0138	(0.0113)
Renewal	5.735***	(0.557)
Switch	-3.985***	(0.831)
Observations	13,662	
R-squared	0.470	

Note: This table presents results from an OLS regression of mortgage rates (in basis points) on observables. We include year-quarter fixed effects, region fixed effects, and lender fixed-effects. Units for loan size 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. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

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 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.

3.1 Preferences and Costs

Borrower's 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 to offer 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, we assume that this initial offer cannot be recalled.[21] She will choose a subset of available lenders as her choice set $n^t \subseteq N^t$, maximizing her expected net benefit from searching, in which the home bank is always included. The borrower then negotiates multilaterally 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:

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

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.

The borrower rejects p_0^t if she expects the reduction in price due to search and negotiation outweigh the search costs. The choice set (n^t) is optimally chosen to balance the search cost incurred and marginal saving in price from adding an extra bank to the set. It is hence determined by the borrower's search decision and location.

Since products are homogeneous, the borrower has no special preference for any lender

[21] 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.

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 $F(\cdot)$. For example, a part of it can be the cost of retail deposits. The 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.

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 multilateral negotiation process is approximated as an English auction:

the borrower obtains quotes from all lenders in the choice set and 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 borrower and lenders learn about borrower preferences and 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.[22] 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).

Notice 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 stays the same (N, λ) or are determined by a new draw from a certain distribution $(c^{t+1}, \kappa^{t+1}, \boldsymbol{\omega}^{t+1})$.

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.

[22] It is straightford to allow borrowers having different switching costs from mortgage relationship ($t > 1$) and pre-mortgage relationship ($t = 1$).

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 $n^t \geq 2$, the borrower puts multiple lenders into competition. Lenders compete in expected utility via an English auction. We use an English auction to approximate multilateral negotiation because it captures two important features in the process: (1) the borrower uses the best offer in hand to extract better quotes, and (2) lenders are 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 $\tilde{b}^t$, then lender j would stay in the auction and keep bidding as long as the present value of winning at $\tilde{b}^t$ is greater than the present value of losing the auction:

$$\begin{aligned}\tilde{b}^t - c_j^t + \sum_{\tau=t+1}^{T} \delta^{\tau-t} E[\Pi_j^\tau(h^\tau, \boldsymbol{\omega}^\tau, \kappa^\tau, N, \lambda)|h^{t+1} = j] \\ \geq \sum_{\tau=t+1}^{T} \delta^{\tau-t} E[\Pi_j^\tau(h^\tau, \boldsymbol{\omega}^\tau, \kappa^\tau, N, \lambda)|h^{t+1} \neq j],\end{aligned} \tag{2}$$

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. 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:

$$b_j^t(c^t, \omega_j^t) = c^t + \omega_j^t - \delta(W^{t+1} - L^{t+1}). \tag{3}$$

Lenders might bid to a price level 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 the future incumbency advantage. Given that it depends on the home bank's profit and hence the borrower's search decision, we show exactly how it can be calculated after solving the home bank's and the borrower's problems in the initial quote stage (see subsection 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:

$$\bar{v}^t - \lambda \mathcal{I}_{j \neq h^t} - p_j^{t*} + \rho U_j^{t+1} = \max_{k \neq j} \{\bar{v}^t - \lambda \mathcal{I}_{k \neq h^t} - b_k^t + \rho U_k^{t+1}\}, \tag{4}$$

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 (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:

$$p^{t*}(s^t) = \begin{cases} c^t - \delta V^{t+1} + \omega_{(2)}^t + \lambda, & \omega_{h^t} - \lambda = \omega_{(1)}^t \\ c^t - \delta V^{t+1} + \omega_{(2)}^t, & \omega_{h^t} - \lambda \leq \omega_{(2)}^t \end{cases} \tag{5}$$

where ω_{h^t} is the home bank's idiosyncratic match value and $\omega_{(k)}^t$ denotes the k^{th} order statistic among $(\omega_{h^t} - \lambda, \omega_1, \omega_2, \cdots, \omega_{n^t-1})$.[23] Equation (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 *ex ante* for the *ex post* rent V^{t+1} in the future periods. The home bank clearly enjoys an incumbency advantage originating from the switching cost λ.

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

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.[24]

Given p_0^t and the equilibrium pricing function (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 $\omega_{-h^t} = \min_{j=1,2,\cdots,n^t-1}\{\omega_j^t\}$ 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 accepting the initial offer, taking into account the expected utility loss from switching.

$$\bar{\kappa}_l^t = \begin{cases} 0, & l = 1, \\ p_t^0 - \lambda - (c^t - \delta V^{t+1} + E[\omega_{(2)}^t|n^t = l]), & l = 2, 3, \cdots, N. \end{cases} \tag{6}$$

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

$$\kappa_l^t = \begin{cases} p_t^0 - \lambda - (c^t - \delta V^{t+1} + E[\omega_{(2)}^t|n^t = 2]), & l = 2, \\ E[\omega_{(2)}^t|n^t = l - 1]) - E[\omega_{(2)}^t|n^t = l]), & l = 3, 4, \cdots, N. \end{cases} \tag{7}$$

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

[24]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.

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:

$$n^t = \text{argmax}_l \, \bar{\kappa}_l^t - (l-1)\kappa^t, \quad l = 1, 2, \cdots, N. \tag{8}$$

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:

$$\bar{\kappa}_l^t/(l-1) > \kappa_{l+1}^t. \tag{9}$$

This condition implicitly requires $\bar{\kappa}_l^t > 0$. If condition (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 (9). Given the search cost distribution $H(\cdot)$, the home bank expects the borrower searching l lenders with the following probabilities:

$$Pr(n^t = l) = \begin{cases} 1 - H(\bar{\kappa}_{\bar{l}^t}^t/(\bar{l}^t - 1)), & l = 1 \\ 0, & l < \bar{l}^t \ \& \ l \neq 1 \\ H(\bar{\kappa}_{\bar{l}^t}^t/(\bar{l}^t - 1)) - H(\kappa_{\bar{l}^t+1}^t), & l = \bar{l}^t \\ H(\kappa_l^t) - H(\kappa_{l+1}^t), & l > \bar{l}^t \ \& \ l < N \\ H(\kappa_N^t), & l = N. \end{cases} \tag{10}$$

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 (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.[25]

[25] 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:

$$\max_{p_0^t} \; [1 - H(\bar{\kappa}_2^t(p_0^t))](p_0^t - c^t + \delta W^{t+1}) + [H(\bar{\kappa}_2^t(p_0^t)) - H(\kappa_3^t)]E[\pi_h^{t*}|n^t = 2]$$
$$+ \sum_{l=3}^{N-1}[H(\kappa_l^t) - H(\kappa_{l+1}^t)]E[\pi_h^{t*}|n^t = l] + H(\kappa_N^t)E[\pi_h^{t*}|n^t = N], \tag{11}$$

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

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

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 (6) and rearranging, the first order condition is equivalent to:

$$\bar{\kappa}_2^t(p_0^t) = \frac{1 - H(\bar{\kappa}_2^t(p_0^t))}{H'(\bar{\kappa}_2^t(p_0^t))}. \tag{12}$$

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:[26]

$$p_0^{t*} = \bar{\kappa}_2^{t*} + \lambda + c^t - \delta V^{t+1} + E[\omega_{(2)}^t|n^t = 2]. \tag{13}$$

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 (5). Knowing the payoff from accepting p_0^t and

[26]Condition (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 (11). Specifically, the condition $\bar{\kappa}_2^{t*} > \kappa_3^t$ must hold.

the expected payoff from searching n^t lenders, the borrower chooses the optimal n^t to solve the search problem (8). Anticipating the search intensity (equation (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 stage if the borrower decides to search:

$$\begin{aligned} W^t &= [1 - H(\bar{\kappa}_2^{t*})](p_0^{t*} - c^t + \delta W^{t+1}) + [H(\bar{\kappa}_2^{t*})) - H(\kappa_3^t)]E[\pi_h^{t*}|n^t = 2] \\ &\quad + \sum_{l=3}^{N-1}[H(\kappa_l^t) - H(\kappa_{l+1}^t)]E[\pi_h^{t*}|n^t = l] + H(\kappa_N^t)E[\pi_h^{t*}|n^t = N] \\ &= \delta L^{t+1} + [1 - H(\bar{\kappa}_2^{t*})]\left(\bar{\kappa}_2^{t*} + E\left[\max\left\{\omega_{-h^t} - (\omega_{h^t} - \lambda), 0\right\} \mid n^t = 2\right]\right) \\ &\quad + \sum_{l=2}^{N} Pr(n^t = l)E\left[\max\left\{\omega_{-h^t} - (\omega_{h^t} - \lambda), 0\right\} \mid n^t = l\right]. \end{aligned} \tag{14}$$

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 of losing can be written as:

$$L^t = \delta L^{t+1} + \sum_{l=2}^{N} Pr(n^t = l)\frac{l-1}{N-1}E\left[\max\left\{\omega_{-j}^t - \omega_j^t), 0\right\} \mid n^t = l\right], \tag{15}$$

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:

$$
\begin{aligned}
V^t &= W^t - L^t \\
&= [1 - H(\bar{\kappa}_2^{t*})] \left(\bar{\kappa}_2^{t*} + E\left[\max\left\{\omega_{-h^t} - (\omega_{h^t} - \lambda), 0\right\} \mid n^t = 2\right]\right) \\
&\quad + \sum_{l=2}^{N} Pr(n^t = l) E\left[\max\left\{\omega_{-h^t} - (\omega_{h^t} - \lambda), 0\right\} \mid n^t = l\right] \\
&\quad - \sum_{l=2}^{N} Pr(n^t = l) \frac{l-1}{N-1} E\left[\max\left\{\omega_{-j}^t - \omega_j^t), 0\right\} \mid n^t = l\right].
\end{aligned}
\tag{16}
$$

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.[27] As a result of the symmetric cost structure and the non-strategic bidding behavior in the English auction, 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.

4 Identification

In this section, we provide an argument for non-parametric identification of the model. In section 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

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

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 of them seems ideal for separating out the search cost distribution from the funding cost distributions.

The second challenge is to disentangle the common cost distribution and the idiosyncratic cost distribution. 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 $H(\cdot|x_i)$.[28]

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

[28] 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.

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 $[\underline{c}, \bar{c}]$.

(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 make sure 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 (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.

4.1 Identification of Switching Costs

We focus on the sub-sample of borrowers located in markets where there are 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 decide to stay with the home banks, P_{h2}.

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

$$\begin{aligned}\underline{P}_h(z) &= \underline{c} + \underline{\omega} + \Lambda(z) - \delta V(z), \\ \underline{P}_r(z) &= \underline{c} + \underline{\omega} - \delta V(z).\end{aligned} \tag{17}$$

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

4.2 Identification of the Search Probability and Discount Factor

Given Assumption 4(i) and Equation (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 (17) by varying z. The lower bound on funding costs $\underline{c} + \underline{\omega}$ is also identified.

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:

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

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

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

The distribution of $\max\{\omega_h, \omega_r\}$ is identified using a standard deconvolution approach.[29] The parent distribution, $G(\cdot)$ is therefore also identified.

4.4 Identification of 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 (12). Therefore, in all markets ($N \ge 2$), 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 (7) because we know the idiosyncratic cost distribution $G(\cdot)$ and the search cost $\Lambda(z)$. The investment incentive $V(z, N = 3)$ can be identified from the price bounds similar to Equation (17).

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

We now have all the elements to calculate the expected values of prices paid by switchers who search 2 lenders $E[P_r|\lambda = \Lambda(z), n = 2, N = 3]$ and the price of those switchers who search 3 lenders $E[P_r|\lambda = \Lambda(z), n = 3, N = 3]$. The probability of switching conditional on the choice set size $n = 2$ and $n = 3$ can also be calculated: $Pr(\omega_{-h} \leq \omega_h - \Lambda(z)|\lambda = \Lambda(z), n = 2)$ and $Pr(\omega_{-h} \leq \omega_h - \Lambda(z)|\lambda = \Lambda(z), n = 3)$. Hence, we can write the expected price paid by switchers with $\lambda = \Lambda(z)$ in 3-bank markets and the overall switching probability:

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

where all the probabilities and expectations are also conditional on $\lambda = \Lambda(z)$ and $N = 3$. Given that we observe the empirical switching probability and the average price paid by switchers in the data, the search intensities $Pr(n = 2|\lambda = \Lambda(z), N = 3)$ and $Pr(n = 3|\lambda = \Lambda(z), N = 3)$ 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.

To summarize, our identification strategy relies crucially on the exogenous variation in switching costs driven by some observable z. We first focus on the sub-sample of borrowers in 2-bank markets to partially alleviate the complexity in price composition induced by the search decisions. We obtain identification of switching costs, discount factor, and the two funding cost distributions in the simplified environment. Then we move to markets with more than two lenders. Given the model primitives, we can back out the search probabilities from the variation in price distribution across different market structures.

The search distribution at the cut-off values is hence identified.

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 (loan size, credit score, and amortization), 5-year bond rate, median income at the FSA level in 2016, time fixed effects (year-quarter), and location fixed effects.[30] 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 as M_i^1. 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 $\text{T1EV}(\gamma\sigma_\omega, \sigma_\omega)$.[31] 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 loan size from entering into the lenders' pricing problem.[32]

The switching cost is assumed to be a linear function of borrower's credit score and median income at FSA level in 2016. For new borrowers, we allow the switching cost from

[30] For location dummies, we use region defined by the first digit of the postal code. Quebec and Ontario are split into 3 and 5 regions, respectively. Northwest and Nunavut territories share the same first digit of postal codes. For other provinces/territories, each province/territory corresponds to a region.

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

[32] Otherwise, the outstanding balance 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 current bid. This would result in a problem of multiple equilibria in the negotiation stage. The problem could be negligible though, because the difference in expected outstanding balance due to different interest rates is minimal. For example, consider a \$100,000 mortgage loan amortizing in 25 years. The outstanding balance in 5 years is \$84,974 and \$85,143 under interest rates 2.7% and 2.8%, respectively. The difference is less than 0.2% of the loan amount, and is unlikely to produce any meaningful impact on lenders' offers.

a pre-mortgage relationship to be different from the regular switching costs for renewers:

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

The search cost is assumed to follow an exponential distribution with its mean determined by the borrower's credit score and the FSA-level median income:

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

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 th negotiation stage conditional on stay/switch and the choice set size. We can then derive the likelihood contribution of each borrower (loyal or switch). Because we do not observe the number of quotes obtained, we first construct the likelihood function conditional on the choice set size n_i and then integrate out n_i^t using the search probabilities. We estimate the model by maximum likelihood.

6 Estimation Results

Table 4 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, lenders' discount factor is estimated to be 0.917 over a 5-year span, which translates into an annual discount factor of 0.983 or annual interest rate of 1.74%. The likelihood ratio test rejects the static model at 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 loan is determined by the observable characteristics and the random shocks. For example, in the first row $\sigma_c = 0.8713$ implies that the standard deviation of the common cost for lending $\$100,000$ over a 5-year term is \$871.3. In what follows, we discuss in more detail the economic magnitude of the model estimates.

Lending Costs. The standard deviation of the idiosyncratic cost distribution is \$286.9,

Table 4: Maximum Likelihood Estimation Results

	Dynamic Model		Static Model	
	Estimate	(S.E.)	Estimate	(S.E.)
Cost shocks				
σ_c	0.8713	(0.0033)	0.8703	(0.0034)
σ_ω	0.2237	(0.0028)	0.2259	(0.0028)
Search cost				
α_0	-0.8195	(0.1653)	-0.8337	(0.1244)
α_{credit}	-0.0497	(0.0211)	-0.0538	(0.0196)
α_{income}	0.0964	(0.0159)	0.1020	(0.0136)
Switching cost				
λ_0	-0.2224	(0.0725)	-0.2594	(0.0815)
λ_{credit}	0.0848	(0.009)	0.0892	(0.0102)
λ_{income}	-0.0063	(0.0022)	-0.0069	(0.0029)
λ_{new}	-0.2460	(0.011)	-0.2334	(0.0109)
Mean common cost				
Constant	14.2020	(0.1492)	14.1616	(0.1573)
Credit	-0.1632	(0.0131)	-0.2263	(0.0122)
Loan size	-0.1203	(0.01)	-0.0331	(0.0104)
Bond rate	0.7226	(0.0478)	0.7398	(0.0519)
Amortization	0.3832	(0.0103)	0.3932	(0.0105)
Income	0.0006	(0.0042)	-0.0137	(0.0044)
Discount factor δ	0.9172	(0.1035)		
Year-quarter FE	Y		Y	
Region FE	Y		Y	
Observations	13,390		13,390	
Log likelihood	-37,050.46		-37,072.44	
LR test ($H_0 : \delta = 0$)			43.96	

Note: Loan size 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. Region is defined as the first digit of the postal code. 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.

which is only about one third of the standard deviation of the common cost shock.[33] This means that most of the price variation that cannot be explained by the observables should be attributed to the unobserved heterogeneity at the borrower level rather than by idiosyncratic differences across banks. This result is consistent with Allen et al. (2019).

The dispersion of the idiosyncratic cost distribution is the key for understanding the

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

borrowers' search decisions. Given the estimated σ_ω and abstracting away from the switching frictions, the expected marginal benefit from adding an extra lender into a 2-bank choice set is $129. This number goes down to only $25 when the borrower is deciding between a 9-bank and a 10-bank choice set.

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. Mortgages with bigger loan size or shorter amortization on average cost less. The median income level in a borrower's local market does not seem to have a significant effect on the lending costs.

Table 5: Summary Statistics of Switching Costs

	mean	sd	p25	p50	p75
	Panel A: New Purchase Contracts				
Low income, Low credit	100	28	84	105	122
Low income, High credit	168	22	150	166	183
High income, Low credit	79	31	60	85	103
High income, High credit	146	24	129	145	162
	Panel B: Renewal Contracts				
Low income, Low credit	345	49	314	356	383
Low income, High credit	450	24	431	450	469
High income, Low credit	328	49	300	339	365
High income, High credit	429	27	409.5	429	448

Note: switching cost of a $100,000 mortgage, measured in dollars. Income and credit score groups are determined by the position relative to the median values within each contract type.

Switching Costs. Table 5 summarizes the estimated cost of switching for a $100,000 mortgage. We break down the switching cost by income level, credit score, and the types of contract. Renewers on average face much higher switching costs than new borrowers, $388 versus $123. This is reasonable due to the extra fees and inconvenience incurred from transferring mortgages across lenders relative to, say, a credit card. Credit score plays a much more significant role than the FSA-level income in explaining switching costs. As we will see below, income plays a role in explaining search costs.

Table 6: Summary Statistics of Search Costs

	mean	sd	p25	p50	p75
	Panel A: Non-searchers				
Low income, Low credit	1.12	0.57	0.72	0.94	1.33
Low income, High credit	1.06	0.53	0.68	0.89	1.26
High income, Low credit	1.57	0.93	0.98	1.30	1.85
High income, High credit	1.51	0.88	0.93	1.25	1.78
Loan size	225.69	111.21	145.66	206.68	285.32
Interest cost	29.09	14.08	18.92	26.73	36.70
	Panel B: Searchers				
Low income, Low credit	0.23	0.16	0.10	0.21	0.36
Low income, High credit	0.22	0.15	0.09	0.20	0.34
High income, Low credit	0.33	0.24	0.13	0.28	0.49
High income, High credit	0.32	0.24	0.12	0.28	0.47
Loan size	227.52	113.83	146.99	207.20	286.14
Interest cost	28.08	13.98	18.11	25.69	35.34

Note: we simulate 100,000 mortgage contracts by sampling borrowers' observable characteristics from the empirical distribution and drawing search cost shocks from the estimated search cost distributions. We then solve the borrowers' search decisions and summarize the search costs by searchers and non-searchers. Units are in $1,000. Income and credit score groups are determined by the position relative to the median values within each of the searcher and non-searcher sub-sample.

Search Costs. Since we do not observe the search cost realizations and search 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 shocks from the estimated search cost distributions. We then solve the borrowers' search decisions and summarize the search costs drawn by searchers and non-searchers in Table 6.

Searchers, on average, have much lower per-bank search costs than do non-searchers:

$274 versus $1,313. On average they obtain 3.5 quotes, one of which is from the home bank. Relative to non-searchers, searchers on average pay less on interest costs in spite of their slightly bigger loans. The median income at the borrower's FSA plays a major role in shaping the search costs. This is intuitive because the process of search and negotiation is time consuming and the time costs can be approximated by borrowers' income.

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 mortgage stress tests recently adopted 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, static merger analyses produce biased results: (i) a static merger simulation overestimates the impact of a merger, and (ii) 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. 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.

7.1 Frictionless Markets

In order 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 10,000 borrowers' new purchase contracts and their subsequent renewal contracts following the steps below:

1. Using only the sub-sample of new borrowers, draw the observable borrower 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 home bank's expected profit, the rival banks' expected profit, and all banks' total expected profit.
4. Assume the borrower's characteristics remain the same at renewal. Given the remaining balance and remaining amortization period, repeat steps 2 and 3 to obtain the equilibrium outcomes for this borrower's renewal contracts.

Benchmark. Table 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 loan size and amortization) unchanged, borrowers are less likely to switch, and pay 4 bps more at renewal 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 the future profits.

Removal of Switching Costs. Column (2) describes a counterfactual where switching costs are eliminated and the only friction is the search costs. Surprisingly, relative to the benchmark dynamic setting borrowers are worse off in terms of the interest costs, both at origination and at renewal. Lenders compete less aggressively because the net continuation value of winning decreases. Renewers are slightly better off in terms of the total cost for financing a mortgage (interest cost plus the search and switching costs), saving on average \$115. However, when compared with the increased total cost at origination (\$320 or about 1% of the total cost), the savings in the future renewal periods cannot make up

Table 7: The Effects of Removing Market Frictions, Dynamic Versus 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	256.048	256.048	256.048	256.048	256.048	256.048	256.048	256.048
Interest cost	31.916	31.935	32.318	31.809	31.661	31.012	31.948	30.987
Total cost	32.294	32.319	32.614	32.107	31.890	31.248	31.948	30.987
Interest rate	2.735	2.734	2.770	2.724	2.713	2.651	2.738	2.649
$\text{Profit}_{\text{home}}$	0.753	0.702	0.683	0.540	0.346	0.176	0.421	0.107
$\text{Profit}_{\text{rival}}$	0.537	0.219	1.051	0.287	1.404	0.459	2.118	0.520
$\text{Profit}_{\text{total}}$	1.290	0.921	1.733	0.828	1.750	0.635	2.539	0.627
V	1.059	—	0.487	—	0.338	—	0	—
# quotes	2.620	2.628	2.708	2.719	6.609	6.609	6.609	6.609
Pr(switch)	0.326	0.324	0.409	0.409	0.740	0.737	0.824	0.824
	Panel B: Renewal Contracts							
Loan size	215.809	215.815	215.956	215.774	215.721	215.488	215.824	215.479
Interest cost	26.508	26.540	26.566	26.069	26.101	25.442	26.180	25.214
Total cost	26.985	27.020	26.870	26.376	26.583	25.925	26.180	25.214
Interest rate	2.773	2.777	2.778	2.729	2.732	2.661	2.739	2.637
$\text{Profit}_{\text{home}}$	1.112	1.053	0.639	0.530	0.522	0.378	0.343	0.104
$\text{Profit}_{\text{rival}}$	0.367	0.129	0.895	0.313	1.031	0.318	1.746	0.527
$\text{Profit}_{\text{total}}$	1.479	1.182	1.534	0.843	1.553	0.696	2.090	0.631
V	1.059	—	0.487	—	0.338	—	0	—
# quotes	2.631	2.637	2.729	2.740	6.609	6.609	6.609	6.609
Pr(switch)	0.190	0.197	0.428	0.429	0.504	0.517	0.832	0.832

Note: We simulate 10,000 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, interest cost, total cost (interest cost plus search and switching costs), home bank's expected profit, rival banks' expected profit, all banks' total expected profit, 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.

for the loss at origination.[34] On the lenders' side, home banks suffer from the removal of switching costs while rival banks are better off. The industry's total expected profit is higher without switching costs, but no bank is willing to lower the costs of switching for its own customers because it only benefits the rival banks. Therefore, if the banks were to endogenously choose the switching cost level, they face the prisoner's dilemma.

The static model predicts quite the opposite for the borrowers' payoff. New borrowers and renewers on average receive a 0.4% and 1.8% reduction in interest costs, respectively. The savings in total cost due to the elimination of switching frictions is 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.

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 home banks' initial quotes. 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 a 0.8% and 1.5% decrease in interest costs at origination and at renewal, respectively. The static model predicts even higher savings in interest costs: 2.9% at origination and 4.1% 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 borrower experience a slightly higher interest costs compared with the benchmark sample, but their total costs on average decrease by 1.1%. The renewers benefit even more, paying 3% lower total costs than the benchmark sample. The static model predicts a 4.1% and 6.7% reduction in total costs

[34]Assuming an annual consumer discount factor of 0.95, the expected savings in the future renewal periods sum up to about $255 in present value. The consumer discount factor needs to be 0.97 to make new borrowers no worse off from the elimination of switching costs. 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.

[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.

at origination and at renewal, respectively.

In summary, the static model overestimates the benefit from removing search and switching costs because it ignores the changes in lenders' investment incentives. In the dynamic world, removing the switching costs alone disadvantages 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.

7.2 Merger Analysis: Static Versus Dynamic

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 2.6 quotes in a market where there are on average 6.6 available lenders. This means that for most borrowers their search decisions and choice set would not be affected by a merger. The impact of the merger on prices is indirectly reflected in the changes in the lenders' investment incentives and may not be noticeable. In order to better compare the merger analysis in a static versus dynamic setting, we therefore focus only 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.

7.2.1 Ex Ante Merger Simulation

We simulate 10,000 contracts from the sub-sample of borrowers in 3-bank markets using the estimated models under both status quo and counterfactual market structures, holding fix the realizations of all random shocks. We abstract away 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 multiple quotes under the status quo market structures. Table 8 summarizes the equilibrium outcomes before and after the merger in both dynamic and static models.

Borrowers on average obtain 2.5 quotes pre-merger. Post-merger, the borrowers would still search and obtain 2 quotes. The dynamic model predicts that new borrowers and

Table 8: The Impact of a Merger

	Dynamic		Static	
	Before	After	Before	After
	Panel A: New Purchase Contracts			
Loan size	215.235	215.235	215.235	215.235
Interest cost	26.521	26.585	26.574	26.737
Total cost	26.965	26.939	27.022	27.093
Interest rate	2.710	2.716	2.714	2.728
Investment Incentive	0.979	1.082	—	—
# quotes	2.503	2.000	2.510	2.000
Pr(switch)	0.455	0.395	0.453	0.390
	Panel B: Renewal Contracts			
Loan size	172.194	172.194	172.194	172.194
Interest cost	21.491	21.593	21.558	21.737
Total cost	21.988	21.980	22.058	22.127
Interest rate	2.752	2.763	2.763	2.783
Investment Incentive	0.952	1.036	—	—
# quotes	2.490	2.000	2.491	2.000
Pr(switch)	0.210	0.160	0.218	0.168

Note: From the sub-sample of borrowers living in markets where only three banks are available, we simulate 10,000 contracts under both current market structure and the counterfactual market structure after merger. We keep only borrowers obtaining multiple quotes (about 63% of the sample). All monetary values are measured in $1,000.

renewers see a 0.2% and 0.5% increase in interest costs after the merger, respectively. The static model predicts a 0.6% and 0.8% increase, respectively. The static merger simulation overestimates the merger impact because it ignores the fact that lenders' investment incentive increases by 10.7% and 8.9% for new purchase contracts and renewal contracts, respectively. 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.

7.2.2 Retrospective Merger Evaluation

Now consider a different case in which the merger has already happened. A researcher wants to perform a retrospective merger 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 would estimate a 0.2% 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 0.5%). 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.

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]

Under the stress tests, borrowers are required to qualify under two debt-to-income ratio restrictions: (1) gross debt-servicing ratio (GDS) $\leq$ 39% and (2) total debt-servicing ratio

[36]See Clark and Li (2019) for a more detailed discussion of the mortgage stress tests, Allen et al. (2017) for a discussion of the effectiveness of macroprudential policies in Canada, and Greenwald (2018) for a discussion of the importance of debt-to-income constraints for explaining debt dynamics in the U.S.

(TDS) $\leq 44\%$, which are defined as follows:

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

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

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] 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 for which they could qualify.[39]

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

[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. The current 5-year modal rate is about 200 bps higher than the median 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]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.

Table 9: The Impact of Mortgage Stress Testing

	All Renewers		Unqualified Renewers	
	No Test	Test	No Test	Test
Loan size	215.548	215.548	308.037	308.037
Qualified amount	322.371	322.371	270.603	270.603
Income	74.564	74.564	65.902	65.902
Interest cost	26.452	26.901	37.140	40.879
Total cost	26.914	27.342	37.790	41.354
Interest rate	2.771	2.801	2.707	2.960
# quotes	2.607	2.607	2.944	2.944
Pr(switch)	0.188	0.169	0.205	0.047
Switching cost	0.942	1.391	1.364	5.108
Obs	6,739	6,739	809	809

Note: We use 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.

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%.[40] The switching costs can then be approximated by the cost of borrowing the excess amount from the private lenders.[41]

Table 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

[40] According to Ratehub.ca, a financial comparison platform in Canada, interest rate offered by private lenders ranges from 10% to 18%.

[41] 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 (having asymmetric banks leads to multiple equilibria). 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).

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 $37,434. These affected renewers need to incur more than 3 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 95% of the affected renewers, and extract much higher profits. The unqualified renewers on average experience a 25 bps increase in interest rates and a 10% increase in interest costs.

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 by Clark and Li (2019), 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.

8 Conclusion

We develop a framework for investigating dynamic competition in markets where price is multilaterally 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' 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.

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A Appendix: 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.

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%						