# Unintended Consequences of Policy Interventions: Evidence from the Home Affordable Refinance Program*

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**Abstract**

We study the unintended consequences of the Home Affordable Refinance Program (HARP) on mortgage borrowers. HARP was intended to help underwater borrowers to refinance after the 2008 crisis. The program, however, unintentionally exacerbated the market power of incumbent lenders by creating a cost advantage for incumbent lenders. To quantify the welfare implications of this cost advantage, we build and estimate a dynamic discrete choice model of refinance decisions where lenders' offers come from a search and negotiation process. The identification exploits a sharp policy change in the middle of the program that gives variations in the program-granted incumbent advantage. Our estimates show that this policy-granted cost advantage has larger impacts than the search friction. In a counterfactual without the cost advantage, borrowers' life-time savings increase by $4,977 on average (3.6% relative to the baseline), with large heterogeneity among borrowers due to unobserved search types. The insight from this study could apply to other policies whose implementation depends on intermediaries with incumbent advantage with respect to targeted agents.

**Keywords:** HARP, Refinancing, Search Friction, Competition, Incumbent Advantage, Financial Crisis, Unintended Consequences

**JEL Classification Codes:** E65, G21, L85

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# 1 Introduction

Economic crises such as the Great Recession often witness significant rise in household debt distress. To help financially distressed households, governments have regularly initiated large-scale mortgage relief programs, since mortgage is the most prominent source of household debt. The direct implementation of such programs often relies on financial intermediaries. For example, in the United States, while CARES Act guarantees individuals with federally backed mortgages the right to pause their mortgage payments in response to COVID-19 induced distress, it does not automatically place their mortgages in forbearance. Borrowers must contact their lender to benefit from this program. Similarly, in Canada, the mortgage deferral program initiated in the early period of COVID crisis requires the borrower to contact their lenders to negotiate specific details on deferral periods and other terms.

The indirect implementation of such programs leaves room for distortions due to market imperfection, which could, unintentionally, lead to incomplete pass through of the benefits. This paper studies the welfare implication associated with a post-2008 financial crisis refinance relief program, the Home Affordable Refinance Program (thereafter, HARP). The financial crisis wiped out home equity for many borrowers, precluding them from refinancing despite of the declining interest rate.[1] In this backdrop, the HARP program was launched to open up the refinance channel for such underwater borrowers in order to boost household consumption. The program was implemented through mortgage lenders, prone to pre-existing frictions in the refinance market. Moreover, the initial design of the program unintentionally exacerbated the frictions by giving incumbent lenders a cost advantage, amplifying their market power.[2] Unsurprisingly, the program did not work as effectively as intended.[3] In this paper, we ask the following questions: How does the incumbent advantage granted by the program distort market outcomes? What is the implication for the consumer welfare?

This paper contributes to the literature by developing a dynamic refinancing model with search friction and price negotiation. By estimating the model using data from HARP, we quantify to what extent the program-granted advantage leads to an incomplete pass-through

[1] Lenders typically require a minimum home equity of 20% when households refinance their mortgage.

[2] The incumbent lender refers to borrowers' current lender to whom they repay their existing mortgage.

[3] Only less than a million households actually refinanced under HARP, while the government originally were targeting to reach up to 8 million, according to the HARP Mid-Program Report.

of benefits by exacerbating the incumbent market power.

Incumbent lenders enjoy advantages in the competition for refinance at least two reasons. The first reason is innate to the refinance market, which is characterized by search frictions. It is costly for borrowers to get additional quotes from lenders other than their incumbent lender, and this allows incumbent lenders to price discriminate based on borrower's outside options and/or search costs (Allen et al., 2019). However, in addition to their natural advantage, the incumbent was also favoured by the design of HARP during the first four years of its implementation. In order to encourage participation of mortgage lenders, HARP protects incumbent lenders from most of the underwriting risk on newly refinanced loans, but refusing to extend this treatment to competing lenders during its first phrase.[4] As a result, HARP created asymmetries in costs of refinancing between the incumbent lenders and their would-be competitors (Amromin and Kearns, 2014). Instead of promoting competition, the program unintentionally augmented the market power of incumbent lenders. In fact, market share of incumbent lenders was 68% under the first phase of HARP compared to around a third in the regular refinance sector (Agarwal et al., 2023). And borrowers that refinance with their incumbent lenders on average pay 12.5 bps higher than those who switched to competing lenders, conditional on observable characteristics.

The HARP program has two features that facilitate our study. First, the HARP data, which is a subset of the U.S. single family loan dataset, has a unique feature—it allows us to link every HARP refinance to its previous mortgage information. Thus we can observe borrowers' switching behaviours and interest rate savings for those who switched lenders with those who stayed with their incumbent lender. Second, the HARP program has a sharp change of policy in the beginning of 2013, four years after its initial launch. The policy change directly removed the aforementioned cost advantage for the incumbent lenders under HARP. The effect of the change is immediate and significant. Market share of incumbent lenders dropped by almost half, similar to that in regular refinance, and average interest savings increased from 154 bps to 196 bps. This before-after comparison, however, cannot be simply extrapolated for the counterfactual calculation of how much borrowers would have saved in absence of the program-

[4]We delay the discussion of the specifics of incumbent underwriting advantage to Section 2 when we provide more institutional background.

granted advantage from beginning. This is because refinance is an inherently dynamic problem for borrowers in the U.S. Those who refinanced earlier are different from those who refinanced later after the change, not only in observed characteristics, but also in unobserved factors. One of the factor is related to search friction in mortgage market (Allen et al., 2019; Allen and Li, 2020). Heterogeneity in borrower's search cost could create selection in terms of refinance timing, with high search cost borrowers might wait longer to refinance. Another unobserved factor is the individual-level house price shock. Borrowers with house value persistently below market-average are hit especially hard by the financial crisis, and the recovery process of their house value is also slower. Thus they are more eager to take up the HARP refinance. The program flaw in the first phase of HARP brings disproportionately more harm to this group of borrowers.

To account for these factors and isolate the effect due to program design, we build a structural model of borrower's dynamic refinance problem with search frictions in the market. The model allows for observed and unobserved heterogeneity of borrowers, which determine their transition process of LTV over time. The outermost shell of the borrower's model is a dynamic discrete choice of whether or not to refinance in each period. This decision involves a dynamic tradeoff between expected reduction in future mortgage payments and a lump-sump cost to refinance in this period. The lump-sum cost includes transaction cost and potential search cost.[5] If the borrower decides to refinance, she first interacts with her incumbent lender, who offers an initial quote from a quasi monopoly position. The incumbent lender knows the borrower's mean search cost, but does not observe the idiosyncratic shock to her search cost, which remains as private information of the borrower. The borrower either takes or rejects this offer, where rejection starts the costly search process. In the search stage, the borrower organizes an English auction among the incumbent and competing lenders, who have heterogeneous costs.

Thus, in our model, borrower's refinance decision depends on the structure and competitiveness of the lending market, as well as the borrower's persistent types, including the mean search cost and house value shocks. When the incumbent has a cost advantage, it charges a higher markup even in the initial offer, because the cost advantage makes the incumbent more

[5] Transaction costs in a mortgage refinancing include application fee, appraisal fee, and title search fee, etc.

competitive with higher expected profits in the search stage , so the threat of search is not as effective. Another factor that enhances the incumbent's market power is a high mean search cost of the borrower. In this case the incumbent gives a higher initial offer to price-discriminate. As the borrower anticipates unattractive rate offers, they are inhibited from refinancing in the beginning.

The identification of the model leverages the policy change in the beginning of 2013, which allows us to separate incumbent advantage due to the program design and search friction. We estimate the model using Simulated Method of Moments (SMM) by matching model's prediction of refinance decision and price to the data. Our estimates show that incumbent lenders have a markup three times higher than the competing lenders under HARP, coming from the advantage of both search and program granted advantage. The main source of the incumbency advantage is the program granted advantage, which accounts for 68% of the total advantage. Since the search decision depends on the offer from the competition stage, borrowers only choose to accept incumbent offer if their net gain from search is not high enough. However, even if borrowers search, they will likely end up staying with their incumbent due to the program advantage. We find the incumbent is able to retain the household with a probability of 62%.[6] Therefore, HARP gives a significant competitive advantage to incumbent lenders that impedes competition from other lenders.

In our counterfactual analysis, we first perform a decomposition exercise. We do so by simulating household refinance decision and the price they will get in an environment without search friction and without program advantage. In the baseline, the model predicts a HARP refinance rate of 15% and an average interest rate saving of 156 bps. If we shut down search, the HARP refinance rate and saving would increase by 4.4% and 9 bps, respectively. If we shut down program advantage, they would increase by 8.2% and 33 bps, respectively. Thus, our model suggests the program advantage plays a larger role. Next, we quantify the welfare improvement with program advantage shut down at the beginning of the program. As more people are able to refinance and get a lower interest rate, the overall default rate would decrease from 6.5% to 4.2%, a 35.5% reduction compared to the baseline. On average, household could increase their life time saving from the program by $4,977, or 3.6% relative to the baseline.

[6] This is calculated as the households who accept incumbent offer divided by households who search.

There is a large heterogeneity on the counterfactual life time savings across households, with a standard deviation of $3,597. This heterogeneity arises from dynamic selection in the refinance market: households who refinanced earlier are those with most incentives to do so. For example, households with higher previous mortgage payment, conditional on everything else, would refinance early to reduce their mortgage payment. These households are also probably the main target of the program. If HARP did not have the design flaw, more households could have refinanced and got a lower price from the program.

Our analysis suggests that for programs whose implementation depends on intermediaries to reach the targeted agents, whether it will work as intended or have unintended consequences that impede the intended efficacy, depends on how the program details interact with the incentives of participants in the relevant markets. In the context of HARP, even if the government fixed the design flaw in the middle of the program which seemingly had a significant boost to its efficacy, it is far from being a salvage to the sizable welfare reduction it has already caused. Policy makes should be extra careful about how the program details affect with pre-existing market powers of market participants.

**Related Literature.** Our paper relates to several strands of literature. First, it is related to the literature that examines the importance of institutional frictions and financial intermediaries in effective implementation of stabilization programs, particularly in housing markets. Piskorski et al. (2010) and Agarwal et al. (2017) study Home Affordable Modification Program (HAMP), another federal program that tries to help households modify their mortgage. They find that lender-specific factors, such as servicing capacity and cost structure, can affect the effectiveness of policy intervention. Abel and Fuster (2019) studies the effect of HARP on household debt and spending. Both Agarwal et al. (2023) and Amromin and Kearns (2014) point out that the design flaw in HARP that increases the pricing power of HARP lenders, which lead to higher interest rates in mortgage markets compared to the regular refinance market. We add to this literature by quantifying the welfare loss associated with program design flaw via estimating a structural model.

This paper also contributes to studies on refinance decisions in the U.S. mortgage market (Keys et al., 2016; Agarwal et al., 2017; DeFusco and Mondragon, 2020). It is a well-documented fact that many US mortgage borrowers do not refinance even in presence of seemingly large financial gains from doing so. This literature focuses on borrower specific factors such as inattention or liquidity in explaining their refinancing decisions. While such borrower specific factors can also help account the muted response to HARP, our paper emphasizes the search friction and imperfect competition of financial intermediaries in explaining part of this shortfall. Closely related, Ambokar and Samaee (2019) explore the role of search costs in explaining such inaction by developing and estimating a dynamic discrete choice model of refinancing with search friction. Our model is different in two aspects. First, we highlight the special position of the incumbent lender in refinance. We give the incumbent lender a first-mover advantage, permitting an initial quote from the incumbent to preempt the borrower's search efforts. Second, we allow a price negotiation framework embedded in the search process. The incumbent could revise its offer later if the borrower turned the initial offer down and presented him with a competing offer after search.

Finally, our paper fits into the literature that examines the market power in consumer finance market. Previous literature (Woodward and Hall, 2012; Honka, 2014; Scharfstein and Sunderam, 2016; Allen et al., 2019; Allen and Li, 2020; Agarwal et al., 2020) has documented various sources that give rise to market power. We add evidence to this literature by studying the U.S. refinance market, and highlighting the role of stimulus policy on market power. Our paper is most closely related to Allen et al. (2019), who proposes a search and negotiation framework to quantify the magnitude of incumbent advantage in Canadian mortgage market. The search and negotiation process in our model is simpler than their model since we assume no recall of initial offer in the auction stage, and this simplification gives us a closed-form solution of the initial offer and distribution of competitive offers. This allows us to embed this search and negotiation process into the dynamic refinancing problem of the borrower, and check its implication for the timing of refinance decisions and dynamic selections. Another related paper, Allen and Li (2020), examine the dynamic competition in market with search and price negotiation. They focus on the setting where the timing of refinance is fixed and does not involve the borrower's dynamic decision. In our paper, we focus on the dynamic problem of borrower's refinance decision, and treat lender's problem as static.[7]

[7]We introduce the correlation between the search cost type and expected loan duration in a reduced-form way.

The remainder of the paper is organized as follows. Section 2 provides some institutional background about HARP. Section 3 describes in detail the data source used for the analysis and then use the data to document some key patterns of the program feature. Section 4 presents the model. Section 5 discusses the estimation procedure and identification. Section 6 shows the estimation results. Section 7 performs counterfactual simulations. Section 8 concludes. Additional technical details and tables/figures can be found in the appendices.

# 2 Program Background

This section provides some background information about HARP. We start with a discussion of the U.S. mortgage market before and during the financial crisis when HARP was created by the government. Then we discuss the unintentional program design that gives the incumbent lender a cost advantage, which results in a lack of competition under HARP.

## 2.1 U.S. Mortgage Market

The U.S. mortgage market is organized into two segments, a primary and secondary market. The primary mortgage market is where borrowers and lenders meet and negotiate lending terms to create a mortgage transaction, while the secondary mortgage market trades mortgage loans and mortgage backed securities (MBS). The primary buyers in the secondary mortgage market are government sponsored enterprises (GSEs), Fannie Mae and Freddie Mac, which purchase the mortgages from the primary market. After acquiring the mortgages, they bundle them into MBS, which are later sold to investors. As the guarantors, GSEs guarantee full payment of interest and principal to investors on behalf of lenders. In return, they charge lenders an upfront guarantee fee. Mortgage lenders that securitized loans through GSE typically retained mortgages' servicing right, which is the main source of cash flow for mortgage lenders.[8] Therefore, mortgage lenders are essentially the intermediaries between the households and the GSEs.

The majority of mortgage contracts that GSEs acquired from lenders is fixed rate. They

[8]The role as a servicer includes collecting payments, advanced them to the MBS trustee, and engaged in a variety of loss mitigating actions on delinquent loans. The terms "servicer" and "lender" are usually used interchangeably.

amortize over long time periods, usually 15 or 30 years. In the U.S., most borrowers can repay their mortgages in full at any point in time without penalties. This is usually done by refinancing their mortgages backed by the same property (but could be with a different lender), and that becomes the new mortgage for the borrowers. Therefore, when the interest rates goes down, mortgage borrowers can take advantage of that by refinancing their loans. However, since the new mortgage needs to be underwritten, its availability depends critically on the borrower creditworthy and the borrower having enough equity in their home. Traditionally, lenders require a LTV ratio no more than 80% for a refinance transaction, although the maximum they are willing to accept is 95% if the borrower is willing to pay mortgage insurance premium upfront.

Although historically the market for mortgage refinancing functioned smoothly, it encountered strong headwinds during the 2008 financial crisis, when the home prices dropped sharply. The phenomenon of owing more on the house than it is worth is known as being "underwater". Despite the lowering interest rate and the potential benefits from refinancing, those "underwater" households were unable to do so because their LTV were ineligible for the regular refinance market.

As a response, the federal government, working with Fannie Mae and Freddie Mac, developed HARP in 2009 to expand the set of borrowers who could refinance their loans. The goal is to help those borrowers regain access to the refinance market, which can lower their mortgage payments and thus reduce mortgage default rates. The program waived the maximum LTV cap of 80% in the regular refinance market and allowed borrowers with insufficient equity to refinance their mortgages by extending federal credit guarantee on those loans.[9] Absent HARP, borrowers with a LTV ratio above 80% would not qualify for regular refinancing of their mortgages. However, the program only allows each household use once. Once a household refinance their mortgage under HARP, they cannot refinance under the program anymore.

[9]The upper limit for the LTV was 105% at inception, and then was lifted to 125% in late 2009 and eventually removed in December 2011. Other than the LTV ratio greater than 80%, the program also include some other requirements such as the borrowers cannot have delinquency record in previous 12 months. See www.makinghomeaffordable.gov/get-answers/Pages/program-HARP.aspx for more details.

## 2.2 Incumbent Program Advantage

While HARP was designed with good intentions, its implementation relies on the participation of mortgage lenders in the market. During the inception of HARP, the U.S. mortgage market was going through a tightening underwriting standard, presumably because the large amount of poorly underwritten loans before the crisis. When a loan was originated, the originator needs to certify the truthfulness of information collected, such as income, assets, and house value. Such certification is known as representations and warranties (R&W). Mortgage investors and GSEs started aggressive audits for possible R&W violations on every defaulted loan in the wake of the financial crisis. Given the ambiguities about the program's treatment of R&W, lenders were reluctant in participating the HARP program because they need to invest additional resources to verify the original R&W. Furthermore, any mortgage that was found to be in violation of its original R&W will be returned to the lenders, who would then bear all of the credit losses. Such risk is called the "put-back" risk, which is the main liability for the lenders in the HARP program (Agarwal et al. (2023), Amromin and Kearns (2014)). In Figure 1(a), we plot the proportion of put-back, calculated as the number of put-back divided by the number of default loan. In Figure 1(b), we plot the default ratio by LTV group, calculated as the number of default divided by the total number of loans. These figures confirm that the industry description is consistent with the data.

This issue of ambiguities about the program's treatment of R&W was realized by the policymakers. As a response, the program has lessened the underwriting requirements and the attendant R&W. However, this only applied to the mortgages originated by the incumbent lender - the original lender of the mortgage before refinanced through HARP. The incumbent lender thus faced a lower put-back risk, compared to all other participating lenders of the program. This asymmetry of the program design, while has a good intention of encouraging lender participation, unintentionally creating an unlevelled playing field toward the incumbent lenders by giving them a cost advantage in originating the mortgage.

With continuing communication between lenders and GSEs regarding R&W liability, policymakers made two more clarifications in terms of R&W violation reviews, which went into effect in January 2013. These include a sunset provision for R&W reviews, setting the time

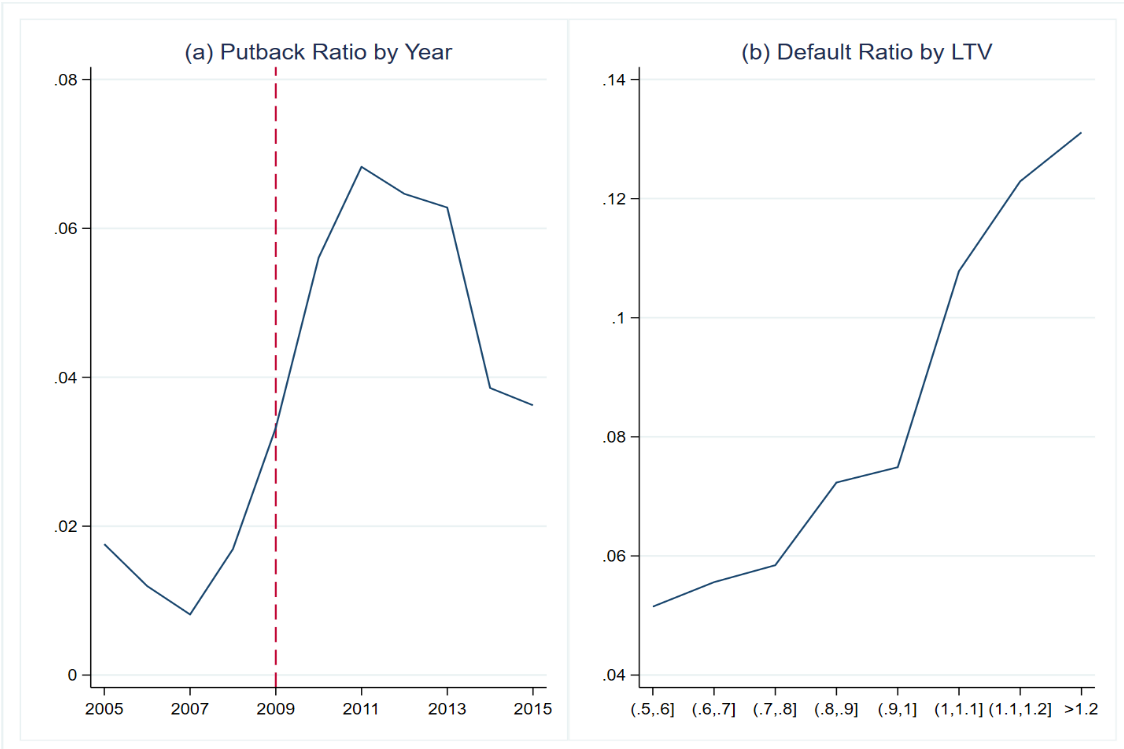


Figure 1: Tightening Underwriting Standard during HARP

Figure 1(a) shows the the put-back risk became particularly pronounced when HARP was launched when mortgage investors and GSEs began conducting aggressive audits for possible R&W violations on every defaulted loan. Figure 1(b) then shows the risk of default was considered to be particularly high in the case of low-equity and underwater loans targeted by HARP, so mortgage lenders regarded R&W as a major liability in the program.

frame over which such reviews could be done at 1-year for HARP transactions, and clarified which violations were subject to the sunset and which were severe enough (e.g. fraud) to be subject to life-of-the-loan time frame (Agarwal et al. (2023)). Importantly, this criteria apply to both the incumbent and competing lenders. Thus, while put-back risk still existed, this change removed the incumbent advantage created earlier in the program.

## 3 Data

Our data comes from three sources. The first is the single family loan-level data complied by GSEs. The second is the data for HARP, which is a separate data that GSEs publish in addition to their main data. The third is the housing price index which measures price movement of single-family houses. We then use the data to document some key patterns of the program feature.

### 3.1 Data Source

**GSE Single Family Data** GSEs started to publish the single family loan-level data to support the risk sharing and transparency encouraged by their regulator, Federal Housing and Finance Agency (FHFA). The data starts in 2000 and is updated quarterly. It consists of two parts: acquisition and performance. The acquisition file provides characteristics of loans that are acquired by GSEs at the loan origination level. Loan characteristics that we observe include credit score (FICO), LTV ratio, debt-to-income (DTI) ratio, loan amount, loan purpose (e.g., home purchase, no cash-out refinance, cash-out refinance), quarter of origination, property zip code and the name of lending institution. The performance file is a panel that provides monthly credit performance, which includes the monthly loan balance and delinquency status. The loan exits the performance file if it was terminated by the borrower via prepay/refinance or foreclosure.

**HARP Data** GSEs also publish a separate data that includes the acquisition and performance file for those who participated HARP. A crucial feature of this data is that it provide us a one-to-one mapping of HARP participants with their pre-HARP transaction. This allows us to identify the households who were refinanced under the program, as well as constructing the key variables of the analysis such as whether they refinanced with their incumbent lender and what is the interest rate reduction they get from HARP.

We combine the main GSEs data and HARP data to construct a panel of loan sequences. An loan sequence is the complete span of time a loan is active until it is terminated. For each sequence, we only observe updated and accurate information (FICO, LTV) at termination for those people who participated in HARP since we are able to match them with the unique loan-id. For all other loans (i.e. those who did not take HARP), we only observe if and when they terminated their mortgage due to either default or refinance, but not if they refinance with their incumbent and the interest rate reduction.

**House Price Index** To create the loan sequence, we need to estimate current LTV, which determines if the household is eligible for the program and also the interest rate they will get. The numerator is straightforward, which is essentially just the loan balance which we observe in each period. To impute current house value in the denominator, we use the FHFA mean house price (HPI) at 3 digit zip level. This index measures average price changes in repeat sales or refinancing on the same properties. This information is obtained by reviewing repeat mortgage transactions on single-family properties whose mortgages were purchased or securitized by GSE. We start with house price at origination, and update it on a quarterly basis using our price indexes. Noise in the denominator can arise in different ways. For example, values for distressed properties are likely to be overstated because they probably were receiving lesser maintenance and repair-related investment, in which case current LTV could be underestimated. In Section 5, we discuss how mitigate this problem by providing an estimation of idiosyncratic housing shock.

### 3.2 Descriptive Analysis

**Summary Statistics** Table 1 reports the summary statistics for a number of variables of interest. Panel A is the main data. This sample contains people who purchase house before the crisis during 2003-2006. These are all purchase loan with 30-year fixed interest rate. Their LTV is on average 80%, or 20% down payment, which is the most common mortgage contract for purchase transaction. The mean of initial interest rate and loan size is 600 bps and $174,000, which imply the mean annual mortgage payment for those households is $12,000.

Panel B then reports the HARP program takers among those from panel A. We report the characteristics for HARP takers separately before and after the mid-HARP policy change on underwriting standards between incumbent and competing lenders which took place in 2013. First of all, FICO score for HARP takers actually increases from 730 to 750, presumably because HARP has a requirement that borrowers cannot have a missing mortgage payment in 12 consecutive months. However, LTV for those borrowers increased from 0.79 to 1, suggesting a loss of home equity for those households as a consequence of the 2008 housing crisis. The (refinance) interest rate that households obtained from the program is 450 bps between 2009-2012, compared to 415 bps between 2013-2018, a period when the market interest rate (i.e. cost of credit) also decreased.

The next two rows show the degree of the incumbent advantage granted by the program. Market share is 68% for incumbent lender during the first half of HARP, compared to a

Table 1: Loan-Level Summary Statistics

Panel A: GSE Single Family Data, 2003-2006

| | Mean | S.D. |
|---|---|---|
| FICO Score | 730 | 50 |
| LTV | 0.79 | 0.09 |
| Interest Rate (bps) | 600 | 45 |
| Loan Size (1,000$) | 174 | 77 |
| # of Observations | 1,627,723 | |

Panel B: HARP Refinance, 2009-2018

| | 2009-2012 | | 2013-2018 | |
|---|---|---|---|---|
| | Mean | S.D. | Mean | S.D. |
| FICO Score | 750 | 53 | 733 | 62 |
| LTV | 1.00 | 0.23 | 1.03 | 0.22 |
| Interest Rate (bps) | 450 | 61 | 415 | 54 |
| Incumbent Market Share | 0.68 | 0.42 | 0.38 | 0.45 |
| Rate Reduction (bps) | 154 | 63 | 196 | 61 |
| Previous Rate (bps) | 611 | 42 | 603 | 40 |
| Previous Balance (1,000$) | 225 | 94 | 192 | 86 |
| # of Observations | 113,095 | | 60,902 | |

This table presents descriptive statistics for the data source used in this paper. Panel A shows the statistics for the parent data, which is the main GSE data that contains purchase loan from 2003-2006. Panel B then presents the HARP takers among those in Panel A. This is separated by those who participated HARP before the mid-HARP policy change on underwriting standards between the incumbent and competing lenders.

regular refinance market where the incumbent market share is 28% to 33% across different years (Agarwal et al. (2023)). The market share becomes close to the regular sector level after the policy change in 2013. In terms of the interest rate reduction (refinance saving), we find on average households who refinance before the policy change saving 38 bps lower compared to households who refinanced after the policy change.

The last two rows show evidence of dynamic selection of refinance. On average, households who refinance early are those who have the most incentive to do so. On average, they have higher previous interest rate as well as higher balance. Overall, we see households took the program during the first half of the program on average have larger previous mortgage payment of $4,000. In Appendix A, we provide further details of the program by showing the pattern for each year.

**Search Friction** Previous literature has documented that borrowers with similar characteristics obtain mortgages with substantially different interest rates in the United States, and a leading explanation of this dispersion is consumer search. Is search friction also present in our data? To show this, one would show that two borrowers in the same market, at the same time, with the same characteristics, paid different mortgage rates. Following earlier literature, we estimate the following specification:

$$r_{itm} = \alpha + \beta \cdot X_{itm} + \mu_t + \mu_m + \epsilon_{itm} \quad (1)$$

where $r_{itm}$ represents the refinance rate of borrower $i$ at time $t$ in market $m$. $X_{itm}$ includes borrower's characteristics, such as FICO score, LTV, mortgage balance, and previous interest rate. In order to compare borrowers in the same market, we condition on market fixed effects (three digit zip code), and on time (year-quarter) fixed effects, in order to compare borrowers at the same point in time.

The result is presented in Column 1 of Table 2. As expected, interest rate is positively correlated with the riskiness of the mortgage. However, conditional on the mortgage characteristics, a substantial amount of residual rate dispersion remain, as can be seen from Figure 2. A borrower at the 10th percentile of the distribution pays an interest rate that is 72 bps lower than that paid by the borrower at the 90th percentile of the distribution. We find a similar magnitude of price dispersion to those presented in Allen et al. (2014), who find that the standard deviation of residual retail mortgage spreads of 50 bps, compared with 45 bps in our data. Meanwhile, Gurun et al. (2016) find a coefficient of variation of 0.23 in their data on U.S. fixed rate mortgages, while ours is 0.29.

Table 2: Descriptive Analysis

| | (1) | (2) |
|---|---|---|
| Sample: | HARP Loans | HARP Loans |
| Dep Var: | Int. Rate | Int. Rate |
| Incumbent | | $0.125^{***}$ |
| | | (0.001) |
| Post | | $-0.145^{***}$ |
| | | (0.001) |
| Post × Incumbent | | $-0.186^{***}$ |
| | | (0.001) |
| log(FICO) | $-0.426^{***}$ | $-0.377^{***}$ |
| | (0.003) | (0.003) |
| LTV | $0.213^{***}$ | $0.196^{***}$ |
| | (0.001) | (0.001) |
| log(Balance) | $0.066^{***}$ | $0.076^{***}$ |
| | (0.000) | (0.000) |
| Prev. Rate | $0.173^{***}$ | $0.172^{***}$ |
| | (0.001) | (0.001) |
| Market FE | Yes | Yes |
| Year-Qtr FE | Yes | Yes |
| Observations | 173,997 | 173,997 |
| R-squared | 0.71 | 0.74 |

This table reports the regression coefficients in descriptive analysis. Column 1 is the result for Equation (1) and Column 2 is the result for Equation (2). Both estimations use HARP loans (i.e. data from Panel B of Table 1) and the dependent variable is HARP refinance interest rate.

**Mid-Program Change** As described in Section 2.2, in an effort to encourage lender participation, the program rules imposed a lesser legal burden on existing (incumbent) servicers in the first part of the program. From January 2013 the program rules were changed significantly. To establish a direct connection between this rule change and the incumbent advantage, we run the following specification:

$$r_{itm} = \alpha + \beta \cdot X_{itm} + \gamma \cdot I_{itm} + \delta \cdot \text{Post}_{im} + \theta \cdot I_{itm} \times \text{Post}_{im} + \mu_m + \mu_t + \epsilon_{itm} \tag{2}$$

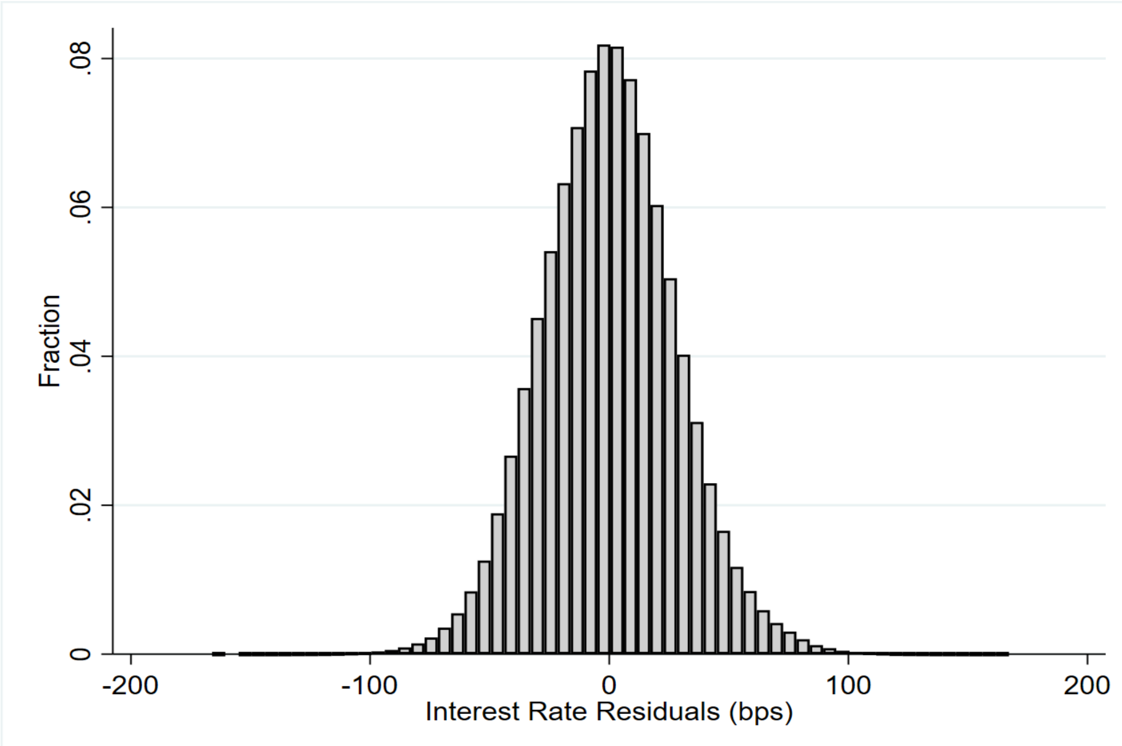


Figure 2: Interest Rate Residual

This figure plots the distribution of the residuals from Equation (1). The standard deviation is 45 bps and the coefficient of variation is 0.29.

where $I_{itm}$ is a dummy variable that equals to 1 if the HARP refinance is originated from the incumbent lender, and $\text{Post}_{im}$ is another dummy variable equals to 1 for loans refinanced during the second half of HARP (2013-2018) after the rule change regarding underwriting costs between incumbent and competing lenders.

Column 2 of Table 2 reports the results. During the first half of the program, borrowers with incumbent lenders on average pay 12.5 bps higher than those switched to competing lenders. After the policy change, interest rates dropped significantly for both stayers (14.5 bps) and switchers (33.1 bps), which is consistent with the presence of incumbent advantage and the cost-reduction effect of the mid-program policy. Note that the price differential between stayers and switchers is no longer positive after the policy change: it is even negative (18.6 bps). This could be due to borrowers' selection into switchers and stayers: stayers on average have higher search costs, so the incumbent expects a higher loan duration and lower prepayment risk, which brings down interest rates.[10]

In sum, this section shows some key patterns from the program and how it changes before and after the policy change. We also document that search friction is present in our data, and the mid-program change does have implication for incumbent advantage. However, in order to separately identify the magnitude of each source (for the welfare analysis), as well as taking into consideration of (dynamic) selection, we provide a structural model, which we describe in the next section.

## 4 Model

Our model is a dynamic discrete choice model of optimal refinance decision. In our model, a borrower starts with an existing mortgage with its interest rate fixed. At the beginning of each period, she checks her current LTV and decides whether or not to refinance. The LTV determines whether she is eligible for refinance and what rates she could get on her refinance. If she is eligible and decides to refinance, she first contacts the incumbent lender to ask a quote. Based on the quote and realization of her search cost, she decides whether to take the incumbent's offer, or to reject and search for a competitive offer on the market. The competitive offer comes from an English auction among the incumbent and competing lenders, who have heterogeneous costs.

The tradeoff that faces the borrower is that, refinancing this period might lower borrower's interest rate and future monthly payments, but it will also incur a lump-sum fixed cost of refinance, including the transaction cost and potential search cost. The timing of refinance also depends on the expected LTV trajectory, since lower LTV leads to better interest rates on refinance.

There are two simplifying assumptions in the dynamic refinancing problem. First, we assume that once a borrower decides to refinance at the beginning of a period, she commits to the refinance decision. In other words, she either takes the incumbent's initial offer or the competing offer by the end of this period. Second, we assume a borrower only has one refinance opportunity. This is largely driven by our data limitation of observing at most one refinance

[10] We do not find any significant difference in default risk for stayers and switchers.

decision for each mortgage borrower. We also take a stance that the ultimate refinance decision is on borrower and lenders' only role in the model is to offer price.[11]

## 4.1 Borrower's Problem

A borrower's dynamic refinance problem starts from the first year after the mortgage origination, which we denote as the first period ($t = 1$). Let $z$ denote the time-variant state variable, which includes the borrower's LTV, and a market-level measure of cost of fund $c$.[12] Given the amortization schedule of the existing loan, the borrower's current LTV depends on her current home value. We assume that a borrower's home value is subject to not only the market-level housing price shock, but also an individual-specific fixed factor, known by herself and lenders but unobserved to the econometrician. (Details on the transition of LTV is in Section 5.1) Given $q$, the transition of $z = (LTV, c)$ is modelled as an Markov process.

A borrower's search cost in each period is given by $\kappa \cdot \epsilon$, where $\kappa$ is a time-invariant borrower type, and $\epsilon \sim F$ is an i.i.d. shock with mean one. The mean search cost, $\kappa$ is known by market participants but not observed by the econometrician. $\epsilon$ is the borrower's private information, and it is realized only when after the borrower decides to refinance.

In each period $t < T$ where $T$ is the mortgage term, the borrower's decision tree is illustrated in Figure 3. In the beginning of this period, $z$ realizes, based which the borrower decides whether to refinance or not. If not, she has the option of making the decision again next period. If she decides and commits to refinance, she contacts their incumbent lender to get an offer, and observes the realization of her search cost $\kappa\epsilon$. If she takes this offer, she will be spared from any search cost, and live with the new mortgage until the end. If she rejects the offer, she will incur the search cost to start a searching process. In this stage, the incumbent and competing lenders compete in an English auction, and they are subject to i.i.d cost shock $\omega$. The borrower takes the best competitive offer from the searching stage and goes with the

[11] That is, we assume it is always borrower who initiate the refinance process: if the benefit of refinance is greater than cost, then they will refinance. Lenders cannot "reject" a borrower other than offering an (expensive) offer that inhibits the borrowers from refinancing. Studying lender's incentive is also important because lenders are facing the cannibalization problem where it tries to replace their current cash flow. Their problem could also be dynamic as well, as in Allen and Li (2020). These are interesting extensions of our model which we leave for future investigation.

[12] In our empirical specification, we use the coupon rate that is passed through to investors of MBS as measure of $c$.

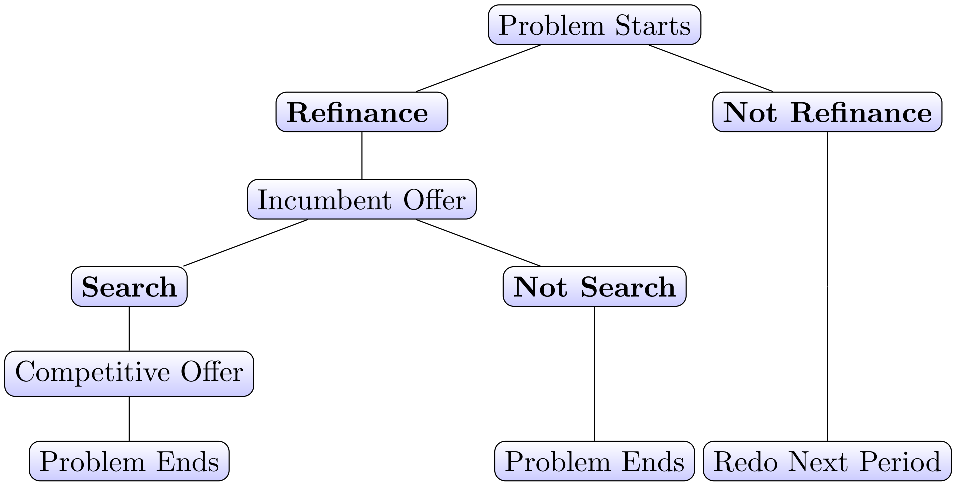


Figure 3: Timing of Borrower Decision

This figure shows the timing of the borrower decision. Borrowers first decide whether to refinance or not. If so, then they decide whether to accept their incumbent lender after getting a free quote, or pay a search cost to gain additional quotes. They have to accept the competitive offer once they decide to search. If they decide not to refinance, they will make the decision again next period.

new mortgage.

To lay out the borrower's dynamic refinance problem with simpler notation, all time-invariant variables, including observed borrower characteristics (income, FICO, geographic location), unobserved borrower types $q, \kappa$, and characteristics of the original mortgage (start year, interest rate, loan term), are omitted in the state variable. We start from the value of not refinancing in period $t$ and waiting for the next period, $V_t^{wait}$. The value of not refinancing is the sum of flow utility and a discounted expectation of continuation values of getting a chance to refinance in the future:

$$V_t^{wait}(z) = u(y - m^0, h) + \beta \left[ p_t^C EV_{t+1}(z') + \left(1 - p_t^C\right) \underline{U}_t \right]. \tag{3}$$

The per-period utility $u(\cdot, \cdot)$ has two components: consumption $y - m^0$ and housing $h$, where $y$ is income and $m^0$ is mortgage payment on her original mortgage.[13] $\beta$ is the discount factor. $p_t^C$ is the probability of continue to repay the mortgage, and it is determined by borrower and loan characteristics as well as loan age.[14] $V_{t+1}(\cdot)$ is the continuation value, i.e. the value of

[13]We abstract way from the borrower's saving choice and other non-mortgage borrowing.

[14]In our empirical specification, we estimate $p_t^C$ by using a survival function. We treat default as an event triggered by exogenous shocks rather than modelling it as a choice.

still having the opportunity to refinance in the future. $\underline{U}_t$ is the life-time utility after default, given by $\sum_{l=t+1}^{L}\beta^{L-l}u(y,0)$ where the housing service is normalized to 0 and $L$ is the last period of the borrower's life ($L > T$).[15]

The expected value of refinance depends on lenders' strategies. Suppose the incumbent's initial offer is a function of $z$ given by $r^I(z)$. The competitive offer, however, is subject to random cost shocks, denoted by $r^C(z,\omega)$. Given lenders' strategy $r^I(z)$, $r^C(z,\omega)$, and the realization of the idiosyncratic component of search cost, $\epsilon$, the borrower decides whether to take the offer, or reject and search. The value of refinance is thus given by:

$$V_t^{refi}(z,\epsilon) = \max\left\{U_t\left(r^I(z)\right),\ EU_t\left(r^C(z,\omega)\right) - \kappa\epsilon\right\} - \phi. \tag{4}$$

$\phi$ is the fixed lump-sum transaction cost associated with mortgage refinance. The expectation in the second term is over $\omega$, which determines the competitive offer. Function $U_t(r)$ gives the life-time utility with the new mortgage refinanced in period $t$ at interest rate $r$. Since we assume that a borrower only refinance once, it follows that $U_t(r)$ is the discounted present value of all future utility flows from period $t$ onwards, where she makes repayment on the new mortgage from period $t$ to $t+T$ (unless being hit by the default shock), and become a mortgage-free homeowner after that. Let $m(r)$ denote the new mortgage payment associated with any interest rate $r$, then $U_t(r)$ can be found recursively by

$$U_\tau(r) = u\left(y - m(r), h\right) + \beta\left[p_\tau^C U_{\tau+1}(r) + \left(1 - p_\tau^C\right)\underline{U}_\tau\right],\ \tau = t, ..., t+T. \tag{5}$$

with the value after the last payment period as the discounted sum of having a home without mortgage until death: $U_{t+T+1} = \sum_{l=t+T+1}^{L}\beta^{L-l}u(y,h)$.

<u>**Search Decision**</u> Let $s$ denote the borrower's search decision. Given Equation 4.1, the borrower will search ($s = 1$) if the net gain from searching is greater than search cost:

$$s = \mathbb{1}\left\{\kappa\epsilon \leq EU_t\left(r^C(z,\omega)\right) - U_t\left(r^I(z)\right)\right\}. \tag{6}$$

[15]Specifically, we fix $L = 50$ in the empirical specification. Since we focus on 30-year fixed rate mortgage, $T = 30$. So borrowers cannot refinance from $t = 21$ to $t = 30$ since the remaining life time is shorter than mortgage term.

**Refinance Decision** Going back to the refinance decision at the beginning of the period, the borrower will refinance if the expected value from refinance is greater than the value of waiting:

$$EV^{refi}(z,\epsilon) > V_t^{wait}(z), \tag{7}$$

where the expectation is over and it follows that the ex ante value of having refinance opportunity in period $t$ is given by:

$$V_t(z) = \max\left\{EV^{refi}(z,\epsilon),\ V_t^{wait}(z)\right\},\ t = 1, ..., T. \tag{8}$$

and the terminal value is given by $V_{T+1} = \sum_{l=T+1}^{L} \beta^{L-l} u(y,h)$, i.e., the discounted sum of utility flows of a mortgage-free homeowner until the end of life.

## 4.2 Supply

We now discuss the problem of mortgage lenders and how price is determined. There are two stages, where the incumbent has monopoly pricing power in the first stage, and in the second stage the incumbent and competing lenders compete in an English auction. As in Allen et al. (2019), the incumbent lender does not commit to the initial offer, permitting the possibility of negotiation if the borrower search for competing lenders' offers.[16]

Depending on LTV, a borrower can be eligible for both HARP and regular refinance.[17] In the Appendix C, we specify the full model with two types of refinance, which differ in the transaction cost and put-back risk.[18] Lenders' offer, in that case, are two dimensional, consisting of both interest rate and product type. In this section, we only focus on the case where a borrower is eligible for only one type of refinance for simplicity.

Throughout this section, we focus on the interaction between a borrower and a lender within one period $t$, so we drop the $t$ index as well as the time-variant state variable $z$ for simplicity, but keep in mind that the equilibrium prices all depend on $z$. There are $J+1$ lenders in the market, which are indexed by $j$. We reserve $j = 0$ for the incumbent lender, and

[16] Different from Allen et al. (2019), we assume the initial offer cannot be recalled.

[17] For example, if a borrower's LTV is in the range of 80% to 95%, she is eligible for both types of refinance.

[18] We allow $\phi$ to be different across HARP and Regular because HARP waived certain fees for borrowers such as appraisal fee and insurance fee.

$j = 1, ...J$ for outside (competing) lenders.

#### 4.2.1 Profit Function

Before discussing how offers are determined, we first specify the expected profit of refinance with a borrower. Here we use $r$ to represent *amortized* interest rate, defined as $r =$ *Monthly Payment/Loan Balance*.[19] For each dollar of loan amount, $r$ is the lender's incoming cash flow, and the outgoing cash flow has two components: the guarantee fee paid to GSEs, denoted as $b$, and cost of fund $c$. Similarly, we convert both $g$ and $c$ to amortized rates, so that $r - g - c$ is the net cash flow a lender can earn by servicing the mortgage. Following Fuster et al. (2013), we assume a lender' revenue is the product of the net cash flow multiplied by a pre-determined multiplier, $M$. Thus we specify the per-dollar profit a lender expects to earn as:[20]

$$\pi_j(r) = M \cdot (r - g - c) - P_j, \tag{9}$$

where $P_j$ is the expected put-back cost of the borrower, which can be different for the incumbent and competing lenders. Specifically, we assume that for a given borrower, all competing lenders share the same put-back cost $\bar{P}$, which is higher or equal to the incumbent's put-back cost:

$$P_0 \leq P_j = \bar{P}, \; j = 1, ..., J. \tag{10}$$

#### 4.2.2 Incumbent Offer

The incumbent lender solves a profit-maximization problem upon receiving inquiry from a borrower. The incumbent knows the borrower's mean search cost $\kappa$ and the distribution of search cost shock $\epsilon$, $F$, but not the realization of $\epsilon$ remains the borrower's private information.

[19] The relationship between amortized interest rate and annualized percentage rate $\tilde{r}$ is given by

$$r = \frac{r\%/12}{1 - (1 + r\%/12)^{-12T}}$$

[20] Note that $M$, $g$, $P_j$ can depend on borrower characteristics and LTV. In the empirical specification, we assume $M$ consists of an observed part (an exogenous function of borrower characteristics) and a residual part that is correlated with borrower's search type $\kappa$. We assume $P_j$ is a function of characteristics of the borrower and the original loan, LTV, and lender type. And $g$ is a function of borrower's FICO and LTV (based on the g-fee matrix from the published annual report).

By Equation 6, the probability of searching is a function of the incumbent's offer $r^I$:

$$p^S(r^I) = \Pr\left(\kappa\epsilon \leq \Delta U(r^I)\right) = F\left(\kappa^{-1}\Delta U(r^I)\right). \tag{11}$$

The net gain from search $\Delta U(r^I) \equiv EU\left(r^C\right) - U\left(r^I\right)$ is the difference between expected utility from getting a competitive offer and accepting the incumbent's offer. Given $p^S(\cdot)$, the incumbent's initial offer comes from the following problem:

$$\max_{r^I} \left[1 - p^S(r^I)\right] \pi_0(r^I) + p^S(r^I) E\Pi_0^s \tag{12}$$

$E\Pi_0^s$ is the incumbent's expected profit in the search stage, which we will specify in the next section. Note that this term is not a function of $r^I$, because the initial offer cannot be recalled. Taking first order condition to the maximization problem renders:

$$r^I(z) = \underbrace{\frac{1 - F\left(\kappa^{-1}\Delta U(r^I)\right)}{f\left(\kappa^{-1}\Delta U(r^I)\right)\Delta U'(r^I)}}_{\text{Markup from search friction}} + \underbrace{M^{-1}(E\Pi_0^s + P_0) + g + c}_{\text{Reserve price}}$$

The first term represents the markup arising from search friction, proportional to the inverse of the hazard rate of offer rejection. It is positive, and increasing with mean search cost $\kappa$ and decreasing with the borrower's net gain from search $\Delta U$, under the uniform distribution of search cost shock. It captures the price discrimination based on the (partial) information about the borrower's search type and outside option. As the borrower's mean search cost is known to be larger, or her outside option of search gets worse, the market power to the incumbent lender becomes larger and more surplus can be extracted.

The second term represents the interest rate rate at which the incumbent lender is indifferent between two stages. It is the reserve price that the incumbent is willing to offer in the first stage. This reserve price consists of two parts: (1) $M^{-1}E\Pi_0^s$ and (2) $M^{-1}P_0 + g + c$. The first part increases with the expected profit of the incumbent lender in the competition stage. The second part is the break-even interest rate, determined by marginal costs. If the incumbent has no advantages over the competing lender, then the expected profits in the second stage is zero, and the reserve price equals the break-even price. The reserve price is greater than break-even price only when the incumbent has cost advantages over the competing lender. In this case, the outside option of search does not constitute as much of a threat to the incumbent, since his advantage still grants him positive expected profits even when competing with the outside lender. Thus, cost advantages like a lower put-back risk allows the incumbent to extract more surplus the initial stage.

#### 4.2.3 Competitive Offer

We now discuss the competition stage to derive the distribution of competitive offer $r^C$ and the expected profits for incumbent lender $E\Pi_0^s$. The stage can be through of as a price negotiation process after the borrower decides to search and compare quotes on the market.[21]

We model this stage as an English auction with heterogeneous firms and potential cost advantage for the incumbent lender. This competition stage commences with each lender observes an idiosyncratic shock to his lending cost for the borrower, $\omega_j$. We assume the distribution of $\omega_j$ is given by a (minimum) Gumbel distribution with mean zero and common scale parameter $\sigma$, which aids the derivation of the distribution of the winning bid.

Define the cost advantage

$$\Delta = \bar{P} - P_0 \geq 0,$$

then the condition for the incumbent to win in the competition stage is:

$$P_0 + \omega_o \leq \bar{P} + \omega_j,\ j \neq 0 \quad \Leftrightarrow \quad \omega_o \leq \omega_j + \Delta,\ j \neq 0$$

When $\Delta = 0$, the incumbent, without any cost advantage, must have the lowest cost shock to win the auction. When $\Delta > 0$, the incumbent can still win the auction even when a competitor has a lower realization of cost shock, due to the cost advantage. To capture this effect, define the effective cost shock

$$\tilde{\omega}_j = \omega_j + \Delta \cdot \mathbb{1}\{j \neq 0\},$$

[21] In practice, this stage is more complicated since we need to take care of the situation where the lender could also bid regular for households whose LTV is between 80% to 95%. The description of this part is more math cumbersome, so we leave the full discussion in Appendix C. The appendix also includes the detailed derivation, including the expectation of winning bid, the distribution of winning product, and each lender's winning probability.

with mean zero for the incumbent, and $\Delta$ for competing lenders.

Let $j^*$ denote the identity of the winning lender, which is the one with the lowest effective cost shock:

$$j^* = \arg\min_j \{\tilde{\omega}_j\}.$$

Following Brannman and Froeb (2000), we derive winning probabilities $p_{j^*}^W$:

$$p_{j^*}^W = \begin{cases} \frac{1}{J \cdot \exp(-\Delta/\sigma)+1}, \text{ if } j^* = 0 \\ \frac{\exp(-\Delta/\sigma)}{J \cdot \exp(-\Delta/\sigma)+1}, \text{ if } j^* = 1, .., J. \end{cases} \tag{13}$$

When $\Delta = 0$, the incumbent wins with the same chance as other lenders, $p_0^W = 1/(J+1)$. When $\Delta > 0$, i.e., the incumbent has the cost advantage, the incumbent wins with higher probability than any competing lender, $p_0^W > 1/(J+1)$, and the incumbent's chance of wining increases with the extent of the advantage $\Delta$.

The winner in the auction charges an interest rate that makes the closest runner-up just breaks even. The runner-up lender's effective cost shock is the lowest among the non-winning lenders, or the second-lowest over all. Using notation from order statistics, let $\tilde{\omega}_{(1)} = \min\{\tilde{\omega}_j\}$ denote the lowest value of $\tilde{\omega}_j$, so the second-lowest value $\tilde{\omega}_{(2)}$ is given by:

$$\tilde{\omega}_{(2)} = \min\left\{\{\tilde{\omega}_0, ..., \tilde{\omega}_J\}/\{\tilde{\omega}_{(1)}\}\right\}. \tag{14}$$

The winning bid, or the competitive offer $r^C$ as mentioned earlier, can be found by the zero-profit condition of the runner-up lender:

$$r^C(\tilde{\omega}_{(2)}) = M^{-1}\left(\tilde{\omega}_{(2)} + P_0\right) + g + c. \tag{15}$$

The expectation of the competitive offer is thus determined by the mean of $\tilde{\omega}_{(2)}$. Based on

Brannman and Froeb (2000), the conditional mean of $\tilde{\omega}_{(2)}$ given $j^*$ is:

$$E\left[\tilde{\omega}_{(2)}|j^*\right] = E\left[\tilde{\omega}_{(1)}|j^*\right] - \frac{\sigma\log(1-p^W_{j^*})}{p^W_{j^*}} \tag{16}$$

$$E\left[\tilde{\omega}_{(1)}|j^*\right] = -\sigma\log\left(J\cdot\exp\left(-\Delta/\sigma\right)+1\right). \tag{17}$$

And the distribution of $\tilde{\omega}_{(2)}$ conditional on $j^*$ wins has an analytical form given by $F_{\tilde{\omega}_{(2)}|j^*}$.[22] The derivation utilizes the property of Gumbel distribution that the minimum value of a set of Gumbel distributed variables also has a Gumbel distribution with the same scale parameter but a lower man.

Given the distribution of the competitive offer, we can calculate the borrower's expected value of search $EU(r^C)$ as:

$$EU(r^C) = \sum_{j^*=0}^{J} p^W_{j^*}\int U\left(r^C(\tilde{\omega}_{(2)})\right)dF_{\tilde{\omega}_{(2)}|j^*}. \tag{19}$$

where we first take expectation over which lender wins, and then take conditional expectation of the winning bid given the identity of the winning lender.

The expected profit from competitive offer for incumbent is given by:

$$E\Pi^s_o = p^W_0 E\left[\pi_0\left(r^C_o\right)-\tilde{\omega}_0|j^*=0\right] = p^W_0 E\left[\tilde{\omega}_{\sim 0}-\tilde{\omega}_0|j^*=0\right] = -\sigma\log(1-p^W_0), \tag{20}$$

which increases with the incumbent's probability of winning $p^W_0$ and thus $\Delta$.

In the more complicated case where a borrower is eligible for both HARP and regular refinance, each lender will observe two cost shocks, one for each type of refinance. Then a lender chooses one type that is more profitable for him to bid in the auction. We show in the Appendix C that this case is equivalent to an asymmetric cost auction as described here,

[22] Conditional on the identity of winning lender $j^*$, the cumulative distribution function of $\tilde{\omega}_{(2)}$ is a weighted average of two distributions:

$$F_{\tilde{\omega}_{(2)}|j^*}(x) = 1-\left[\frac{1}{p^W_{j^*}}\left(1-F_{\tilde{\omega}_{(1)|\sim j^*}}(x)\right)+\left(1-\frac{1}{p^W_{j^*}}\right)\left(1-F_{\tilde{\omega}_{(1)}}(x)\right)\right], \tag{18}$$

where $F_{\tilde{\omega}_{(1)|\sim j^*}}$ is the distribution of the lowest value of $\tilde{\omega}_j$ among all lenders but $j^*$ (not conditional on $j^*$ being the lowest bidder). Thus both $F_{\tilde{\omega}_{(1)|\sim j^*}}$ and $F_{\tilde{\omega}_{(1)}}$ are distributions of the minimum value among a set of Gumbel distributed variables, which are also Gumbel distribution with the same scale parameter. The mean of $\tilde{\omega}_{(1)|\sim j^*}$ is $-\sigma\log(J)+\Delta$ if $j^*=0$, and $-\sigma\log\left((J-1)\exp(\Delta/\sigma)+1\right)$ if $j^*=1,...,J$.

but with different means of effective cost shocks. The definition of effective cost shock is also different, taking into account the borrower's different preferences with HARP and regular refinance. Even in this case, the incumbent's advantage in HARP refinance still grants him higher probability to win and higher expected profits.

# 5 Estimation and Identification

We now discuss the estimation of the model presented in the previous section. We begin by discussing the model parametrization and estimation of empirical objects outside of the model. Then we describe the model estimation procedure through Simulated Method of Moments (SMM), followed by a discussion of how we identify the parameters. We put all the results that we estimate outside the model in Appendix B1-B3.

## 5.1 Parametrization

Before estimating the structural model, we first need to parameterize distributions and functions, and estimate some of the functions "off-model". On the demand side, objects estimated off-model include (1) estimating the repayment probability $p^C$, (2) estimating the transition process of the state variable including LTV. On the supply side, we decompose the multiplier $M$ and the put-back cost $P$ as an observed component multiplied by an unobserved part. We estimate the observed component of $M$ and $P$ outside of the model, and leave the unobserved parts for the structural estimation.

### Demand side

For borrowers, we assume simple linear utility additive in housing service : $u(c, h) = c + h$. It follows that the value of refinance $U(r)$ is linear in $r$, and this helps with analytically solving the competitive offer from the auction (see Appendix C).

**Search cost distribution** Following previous literature (Alexandrov and Koulayev (2018), Ambokar and Samaee (2019)), we assume the search cost type $\kappa$ has a log-normal distribution with mean and variance given by $\mu_\kappa$ and $\sigma_\kappa^2$, respectively. We assume the idiosyncratic search cost shock $\epsilon$ have a uniform distribution on the interval $[2-\tau,\tau]$, so that the mean of $\epsilon$ is 1:

$$\kappa_i \sim LN(\mu_\kappa, \sigma_\kappa)$$
$$\epsilon_{it} \sim U[2-\tau,\tau]$$

**Repayment probability** We estimate the probability of repayment as an exogenous function of $t$ (loan age) and $X_i$ (borrower characteristics, original interest rate and LTV, loan balance, market fixed effect). We use a log-logistic survival function to model the probability of keeping repaying until $t$: $\left[1+(\lambda_i t)^{1/s}\right]^{-1}$, and we parameterize $\lambda_i$ as $\exp\left(-X_i' b\right)$. We use data to estimate $b$ via maximum likelihood method, and the results are shown in Appendix B1. Then we plug in the estimated $\hat{\lambda}$ and $\hat{s}$ to calculate the the probability of continuing making payment in $t+1$ conditional on previous $t$ payments are already made:

$$p^C = \frac{1+\left(t\hat{\lambda}\right)^{1/\hat{s}}}{1+\left((t+1)\hat{\lambda}\right)^{1/\hat{s}}} \tag{21}$$

**Transition of state variables** Now we consider the transition of the time-varying state variable $z_{it} = (LTV_{it}, c_t)$. We use the yearly average coupon rate on the MBS market as the measurement of $c_t$, and estimate a Markov transition process of $c_t$. To estimate the transition of a borrower's LTV, we need to consider borrowers' home value in each period. After loan origination, a borrower's home value is subject to changes over time, and the new home value is generally not observed, which poses an econometric challenge. Although market-level indicators like House Price Index (HPI) can show the average house price changes over time, it masks the important heterogeneity in individual-level home value appreciation/depreciation. In other words, some borrowers might persistently get above or below average house value shock, which leads to differences in their LTV trajectory. Omitting this heterogeneity would lead to measurement error for HARP eligibility. Thus we allow an individual-level time-invariant fixed factor $\xi_i$ in determination of a borrower's home value in addition to market conditions captured by changes in HPI and other indicators. Specifically, we assume borrower

$i$'s home value at period $t$, $HV_{it}$, is given by:

$$\log(HV_{it}) = \beta_0 + \beta_1 \log(HV_{i0}) + \beta_3 \log(HPI_{mt}/HPI_{m0}) + \beta_4 Z_{mt} + \xi_i,\ \xi_i \sim N(0, \sigma_\xi) \quad (22)$$

where $HV_{i0}$ is borrower $i$'s original home value, and $m$ indicates the 3-digit zip code market that borrower $i$ is located in. The market-level observables $Z_{mt}$ include change of local unemployment and local average income. The distribution of $\xi_i$ is normal with mean zero and unknown variance $\sigma_\xi$. Parameters of interest here include $\beta_0, ..., \beta_4$ as well as $\sigma_\xi$.

To pin down the parameters, we utilize the sub-sample of borrowers who refinanced under the HARP program, for whom we are able to observe both the original home value and new home value at the time of refinance. However, this sub-sample of borrowers with HARP refinances is highly selective, so using it to directly estimate (22) would yield biased results for the whole sample of borrowers.

To address this issue, we use a Heckman selection model, where the first stage regression is the binary decision to take the HARP refinance, and the second stage regression is about HARP taker's new house value at the time of refinance. The exclusion restriction is that borrower-specific variables including FICO, original interest rate and LTV affect the refinance decision but not the house value. We discuss the details of this estimation in Appendix B2.

Based on estimates of Equation (22), we can find LTV of a borrower as a function of local HPI and other indicators $Z_m t$, individual house shock type $\xi_i$, and home value and HPI at loan origination: $LTV_{it} = G(HPI_{mt}, Z_{mt} | \xi_i, HV_{i0}, HPI_{i0})$. Thus the transition of $LTV_{it}$ depends on the transition of $(HPI_{mt}, Z_{mt})$, which we estimate as a Markov process using quarterly data over the period 1984-2007 for each state.[23]

**Supply side**

In addition to search cost, another component of the fixed cost of refinance is the transaction cost, $\phi$. As mentioned earlier, we allow $\phi$ to be different across HARP and Regular, and we normalize $\phi_H = 0$ so we estimate the difference ($\Delta_\phi$) between HARP and Regular. The number of competing lenders $J$ is set as a third of total number of lenders in the market, rounded to

[23]Data on HPI is from FHFA, and data on income and interest rates are obtained from the Federal Reserve Board. We discretize the data using the Tauchen method for each state.

the nearest integer.

**Multiplier** We assume the supply side multiplier $M$ consists of an observed part and a residual part. The observed part is the expected loan duration, which is estimated using a log-logistic survival model using borrower characteristics, original interest rate, loan size, LTV, and market fixed effects. (See Appendix B1) The residual part is parameterized as function of borrower's search cost type:

$$\exp\left(\gamma_0 + \gamma_1 \tilde{\kappa}\right) \tag{23}$$

where $\tilde{\kappa}$ is the standardized search type (i.e. $\left(\kappa - E(\kappa)\right)/\text{std}(\kappa)$). The parameters $\gamma_0$ and $\gamma_1$ will be estimated structurally in the next stage.

**Put-back cost** We decompose the put-back cost $P_j$ as the product of the expected cost of a put-back event $P_{cost}$, and the probability of put-back $p_{ij}^{PB}$:

$$P_{ij} = P_{cost} \cdot p_{ij}^{PB}. \tag{24}$$

We estimate the put-back probability $p_{ij}^{PB}$ using a logistic regression, where the regressor $X_{ij}$ includes $Incumbent \times Pre2013$ dummy, $Post2013$ dummy, borrower characteristics, original interest rate, loan size, LTV, market and year-quarter time fixed effects. Results are shown in Appendix B3. We find that the loans originated from the incumbent is on average 1.8% less likely to be put back compared to the competing lenders in the pre-2103 period, and this wedge is not statistically significant after 2013. Using the estimated coefficients of the logistic regression $\hat{\delta}$, our put-back probability is expressed as:

$$p_{ij}^{PB} = \frac{\exp\left(X_{ij}'\hat{\delta}\right)}{1 + \exp\left(X_{ij}'\hat{\delta}\right)}$$

## 5.2 SMM Estimation

The parameters to be estimated is summarized in Table 3. We use the Simulated Method of Moments (SMM). Since this is a finite horizon problem, we solve the model using backward induction. Specifically, we solve value function and the associated policy function (refinance and search) for household at each possible state for 20 period. We also solve the distribution of offers that they can get at each refinance opportunity. Next, we simulate the path of each household's state variables which determines when they will refinance, and then the realized incumbent offer, search decision and offer from the competition stage. We use a random sample of 10,000 households from Panel A of Table 1.

Table 3: SMM Estimation: Parameters

| **Notation** | **Definition** |
|---|---|
| $\mu_\kappa$ | Mean of Logarithm of Mean Search Cost |
| $\sigma_\kappa$ | Std-Dev of Logarithm of Mean Search Cost |
| $\tau$ | Boundary of Idiosyncratic Search Cost |
| $\Delta_\phi$ | Difference of Transaction Cost |
| $P_{cost}$ | Put-back cost parameter |
| $\gamma_0, \gamma_1$ | Parameters in the Multiplier |
| $\sigma_\omega$ | Scale Parameter of Idiosyncratic Cost Shock |

This table summarizes the parameters we seek to estimate from the empirical model using the Simulated Method of Moments (SMM) estimation.

We then match model's prediction of refinance decision and price to the data on program participation and pricing decision. Let $D_{it}$ denotes model prediction on decisions which include HARP Incumbent (HI), HARP Competing (HC), Regular (R) or Wait (W), and let $r_i$ denotes price conditional on taking HARP. The observed outcome from data is denoted as $\hat{D}_{it}$ and $\hat{r}_i$. The moment restrictions $g(\Theta)$, where $\Theta$ denotes the parameters to be estimated, are

$$E_i[X_i(\hat{D}_{it} - D_{it})|\text{Post-2013}]$$
$$E_i[X_i(\hat{r}_i - r_i)|D_{it} \in \{HI, HC\}, \text{Post-2013}]$$
$$E_i[X_i(\hat{r}_i - r_i)^2|D_{it} \in \{HI, HC\}, \text{Post-2013}]$$

where $X_i$ includes borrower characteristics such as FICO, LTV and previous interest rate. We also use an auxiliary moment from HARP survey that 46% of households only consider one lender when they participated the program.

We adopt SMM estimator by minimizing the differences between model prediction and its data counterpart:

$$J(\Theta) = g(\Theta)'Wg(\Theta),$$

where the weighting matrix $W$ is the inverse of the variance-covariance matrix of data moments calculated by bootstrap method.

### 5.3 Identification

The primary identification concern is to separately identify the search cost and program advantage. The key source of variation comes from the mid-HARP program change on the underwriting standard between incumbent and competing lenders. The conditional price from the incumbent before and after the policy change helps to pin down the level of the put-back cost $P_{cost}$, given that the changes in the put-back probability is observed.

Parameters that determines the search probabilities include both the mean of search type $\mu_\kappa$ and the boundary of search cost shock $\tau$. This can be seen by plugging in the distribution of $\epsilon$ in Equation (11):

$$p^S = \min\left\{\max\left\{\frac{\Delta U(r^I)/\kappa - (2-\tau)}{2\tau - 2}, 0\right\}, 1\right\}$$

Both an increase in $\tau$ and a decrease in $\kappa$ can lead to a higher $p^S$. However, $\tau$ does not affect the probability of refinance much, because $\epsilon$ only realizes *after* the refinance decision. For example, a high probability of refinance and a low probability of search is likely a result of low $\kappa$ and low $\kappa$, versus a high probability of refinance with a high probability of search is likely to imply low $\kappa$ and high $\tau$. Thus, the correlation between the probability of refinance and the probability of search helps us to separately identify $\kappa$ and $\tau$, where the probability of search is given by the auxiliary moment from the HARP survey on lender consideration.

Once parameters about search cost parameters and put-back costs are pinned down, we can use the post-2013 incumbent vs competing lender's price differences to identify the remaining parameters on the supply side, namely $\gamma_0$ and $\gamma_1$ in the multiplier $M$. $\gamma_0$ governs the overall price levels, while $\gamma_1$ determines the correlation between $\kappa$ and price. Since borrowers with higher $\kappa$ is more likely to stay with the incumbent, the post-2013 difference between incumbent and competing lender's prices shows how $\kappa$ is correlated with price, thus pinning down $\gamma_1$.

The difference in fixed cost $\Delta_\phi$ is identified by the households who choose regular refinance but are eligible for HARP. Finally, the dispersion parameters ($\sigma_\kappa$ and $\sigma_\omega$) can be identified from the second order statistics such as standard deviation of prices.

## 6 Results

The results of the SMM estimation is presented in Table 4. The parameter estimates are reported in Panel A, and standard error is in the parenthesis, which is calculated using the delta method. The model fit is reported in Panel B. To better interpret these estimates, we transfer everything into dollar term when discussing the results.

Table 4: SMM Estimation Results

**Panel A: Parameter Estimates**

| $\mu_\kappa$ | $\sigma_\kappa$ | $\tau$ | $\Delta_\phi$ | $P_{cost}$ | $\gamma_0$ | $\gamma_1$ | $\sigma_\omega$ |
|---|---|---|---|---|---|---|---|
| 1.9227 | 1.0882 | 1.9883 | 0.2044 | 0.3772 | 0.7104 | 0.3811 | 0.0161 |
| (0.2875) | (0.2521) | (0.2911) | (0.0121) | (0.0244) | (0.0005) | (0.0023) | (0.0028) |

**Panel B: Model Fit**

| | Data Moments | Simulated Moments |
|---|---|---|
| HARP Take-up Rate | 0.12 | 0.15 |
| Incumbent Market Share (Pre 2013) | 0.68 | 0.72 |
| Incumbent Market Share (Post 2013) | 0.38 | 0.41 |
| Mean Incumbent Price (Pre 2013) | 4.61 | 4.58 |
| Mean Incumbent Price (Post 2013) | 4.04 | 4.02 |
| Mean Competing Price (Pre 2013) | 4.46 | 4.42 |
| Mean Competing Price (Post 2013) | 4.06 | 4.11 |

Panel A of table reports the parameters estimated via SMM. Standard error is in the parenthesis, which is calculated using delta method. Panel B shows the model fit by comparing the model predicted moments and data.

On the demand side, the estimated mean search cost is \$683. The results also suggests selection exists in the refinance market: searchers has an average search cost of \$654 versus \$1,614 of non-searchers, and people who refinanced earlier (pre-2013) has an average search cost of \$603 versus \$897 of those who refinanced later (post-2013). This evidence is in line with Ambokar and Samaee (2019) that dynamic selection (on search cost) exists in the refinance market. In terms of transaction cost, we find that Regular refinance is about \$2,044 more costly than HARP.[24] This number is reasonable since the difference between HARP and Regular

[24] Although we normalize the transaction cost of HARP to 0, borrowers are not sure whether he will get a HARP or Regular refinance when he makes refinance decision so he still needs to take this into consideration.

comes from appraisal fee and insurance premium. The magnitude of refinance cost from our estimation is also similar to Wong (2019), who reports an estimate of $2,100. It is a non-trivial cost for borrowers which could inhibit them from refinancing.

On the supply side, the average program advantage to the incumbent is 0.012 per dollar of loan.[25] This advantage is bigger for households that are more costly to originate since we allow put-back probability to be a function of borrower characteristic. For example, the program advantage is higher for households with higher LTV and/or higher previous interest rate, who are probably the main target that the program tries to reach for. In terms of the idiosyncratic cost shock, we find that the scale parameter implies a variance of 0.02 per dollar of loan, which is considerably large.

With the estimates from search cost and program granted advantage, we now calculate the profit margins. Overall, the average profit margin for the incumbent lender under HARP is 0.016 per dollar of loan. That is is almost three times more than the competing lenders, which is 0.006 per dollar of loan. The incumbent profit margin is larger for non-searchers (0.018) than searchers (0.015) since the margin of the initial offer contains both search cost and program advantage. The main source of the incumbency advantage is the program granted advantage, which accounts for 68% of the margin on average across all households. Since the search decision depends on the offer from the competition stage, borrowers will choose to accept incumbent offer if they don't expect gain too much from searching. However, even if borrowers search, they will likely end up staying with their incumbent due to the program advantage. We find the incumbent is able to retain the household with a probability of 62%.[26] This is a larger magnitude compared to Allen et al. (2019), who reports an estimate of 51% in the Canadian mortgage market. Therefore, HARP gives a significant competitive advantage to incumbent lenders that makes it very hard for competing lenders to compete for households.

Finally, Panel B of Table 4 shows the model fit. Our model is able to reproduce the low take up rate of the program, and it also captures some key patterns in the data, such as the price difference and incumbent market share before and after the mid-HARP policy change on

[25]We first calculate the differences in put-back probability between incumbent and competing lenders for each loan using the results from Appendix B3, and multiply the difference with the estimated put-back scale from the structural estimation.

[26]This is calculated as the households who accept incumbent offer divided by households who search.

underwriting standards between incumbent and competing lenders. Overall, the model provides a close enough fit to the data that we are comfortable using it to assess the counterfactual effects of shutting down the program granted advantage to the incumbent lenders.

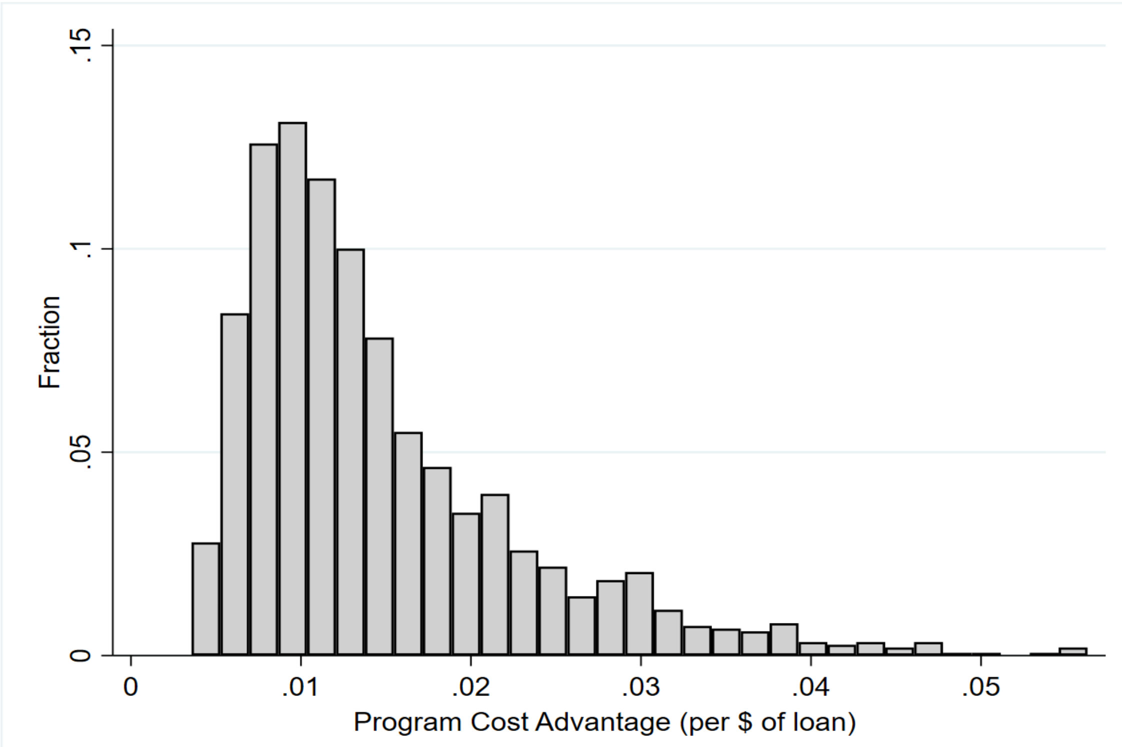


Figure 4: Incumbent Cost Advantage under HARP

This figure shows the estimated cost advantage to the incumbent under HARP. We first calculate the differences in put-back probability between incumbent and competing lenders for each loan using the results from Appendix B3, and multiply the difference with the estimated put-back cost parameter from the structural estimation.

# 7 Counterfactuals

We first perform a decomposition analysis to separately show the effect of search friction and program advantage on market outcome such as take-up (refinance) rate and price. Then, we quantify the welfare implication in terms of consumer surplus and default rate in a case where the program does not have design flaw from the beginning.

## 7.1 Decomposition

What will the program outcome look like if we eliminate the incumbent advantage in the program? To answer this question, we simulate an environment where we eliminate search friction and program granted advantage. The results is presented in Figure 5. In the baseline, the model predicts HARP refinance rate (extensive margin) of 15% and average interest rate saving (intensive margin) of 156 bps. If we shut down both advantages (Neither), we find HARP refinance rate and saving would increase by 13.7% and 42 bps, respectively. Both are pretty sizable increase compared to the baseline model. However, since transaction costs and put-back liability for mortgage lenders remain, many households would still choose not refinance.

To show the impact of each source of incumbency advantage on market outcome, we separately shut down search friction and program granted advantage. If we shut down search (No Search), we find HARP refinance rate and saving would increase by 4.4% and 9 bps, respectively. If we shut down program advantage (No Advantage), they would increase 8.2% and 33 bps, respectively. Thus, our model suggests the program advantage plays a bigger role. This is because households will be stuck with their incumbent if they have no good outside option to negotiate with the incumbent lender. Thus, absent of competition, getting rid of search friction won't help much since there is no incentive for the incumbent lender to offer a competitive rate. In reality, there is probably not much government can do about (completely) eliminating search friction, either. Nevertheless, they can clearly do a lot about program design. Thus, this is what we will focus in the next subsection.

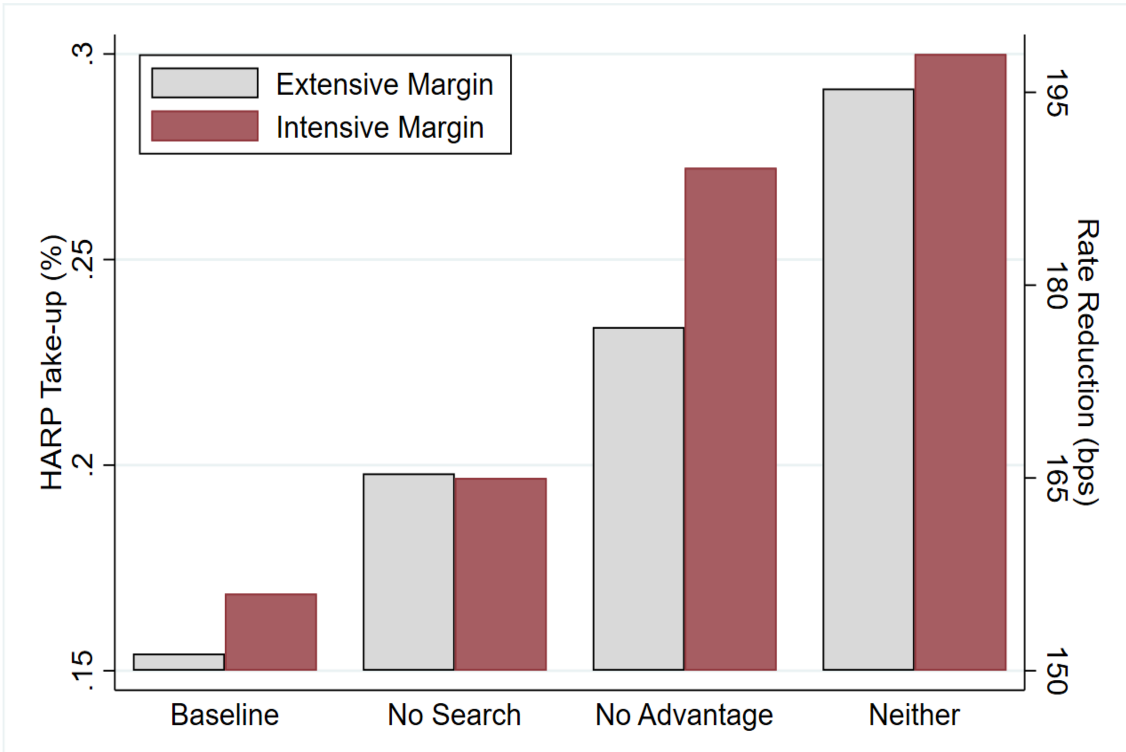


Figure 5: Decomposition: Extensive and Intensive Margin

This figure plots the baseline model prediction of HARP refinance rate (extensive margin) and average interest rate saving (intensive margin). In a decomposition analysis, we separately shut down search friction (No Search) and program granted advantage (No Advantage) to show the impact of each source of incumbency advantage on market outcome.

### 7.2 Welfare Implication of Program Design

We now quantify the welfare improvement with program advantage shut down at the beginning of the program. As more people are able to refinance and get a lower interest rate, we find that the overall default rate would decrease from 6.5% to 4.2%, a 35.5% reduction compared to the baseline.[27] The decrease in default is pretty meaningful, as a lower default rate is good for the government since it provides credit guarantee on these mortgages. If the loan gets default, government needs to defray the cost to MBS investors. It is also good for economics stability, as lower default means lower foreclosure. Foreclosure events can impose significant negative economic and social externalities on homeowners, on communities, and, because of the serial correlation of neighbouring real estate prices, on the housing market in general (Levitin and

[27]Following the literature, default is defined as having at least two missing payments since 24 months of loan origination. We obtain these numbers by simulating the default probability of households according to our estimation of default probability in Appendix B1.

Twomey (2011)).

Next, we turn to consumer surplus, defined as the life time saving (utility gain) from refinancing. We find on average, household could increase their life time saving from the program by $4,977, or 3.6% relative to the baseline, if the program does not have the design flaw at the beginning. However, this masks important heterogeneity. The standard deviation is $3,597 and the welfare increase ranges from less than $2,000 to more than $14,000. Figure 6 draws the distribution of welfare increase, where the top panel splits by previous mortgage payment, and the bottom split by search cost. We define high/low payment (search) as those households with previous mortgage payment (search cost) larger/lower than the median value. On average, borrowers with higher previous mortgage payment enjoy a increase of $6,521, which is two times larger than those with lower previous payment. Similarly, borrowers with low search cost on average have higher welfare increase than those with high search cost. This heterogeneity arises from dynamic selection in the refinance market. Intuitively, households who refinanced earlier are those with most incentives to do so. Households with higher previous mortgage payment, conditional on everything else, would refinance early to reduce their mortgage payment. These households are also probably the main target of the program. The result from search cost are more subtle because search cost is unobserved to policy makers. However, our results do suggest that households with lower search cost will refinance earlier, in line with the results from Ambokar and Samaee (2019). If search cost is correlated with other borrower characteristics (such as income), then it would have welfare implication as well.

In sum, our analysis suggests that if HARP does not have the design flaw from the beginning, more households could have refinanced and got a lower price from the program. This would lower the overall mortgage default rate as well as increase consumer welfare. Thus, the design of the program is very important. In the context of HARP, the original intention is to encourage participation from incumbent lenders, but it unintentionally augments their market power, which ended up inhibiting refinancing. Even if the government fixed the design flaw in the middle of the program, it should have been more careful when designing the programs from the beginning as it has sizable welfare implication, as we discussed in this subsection.

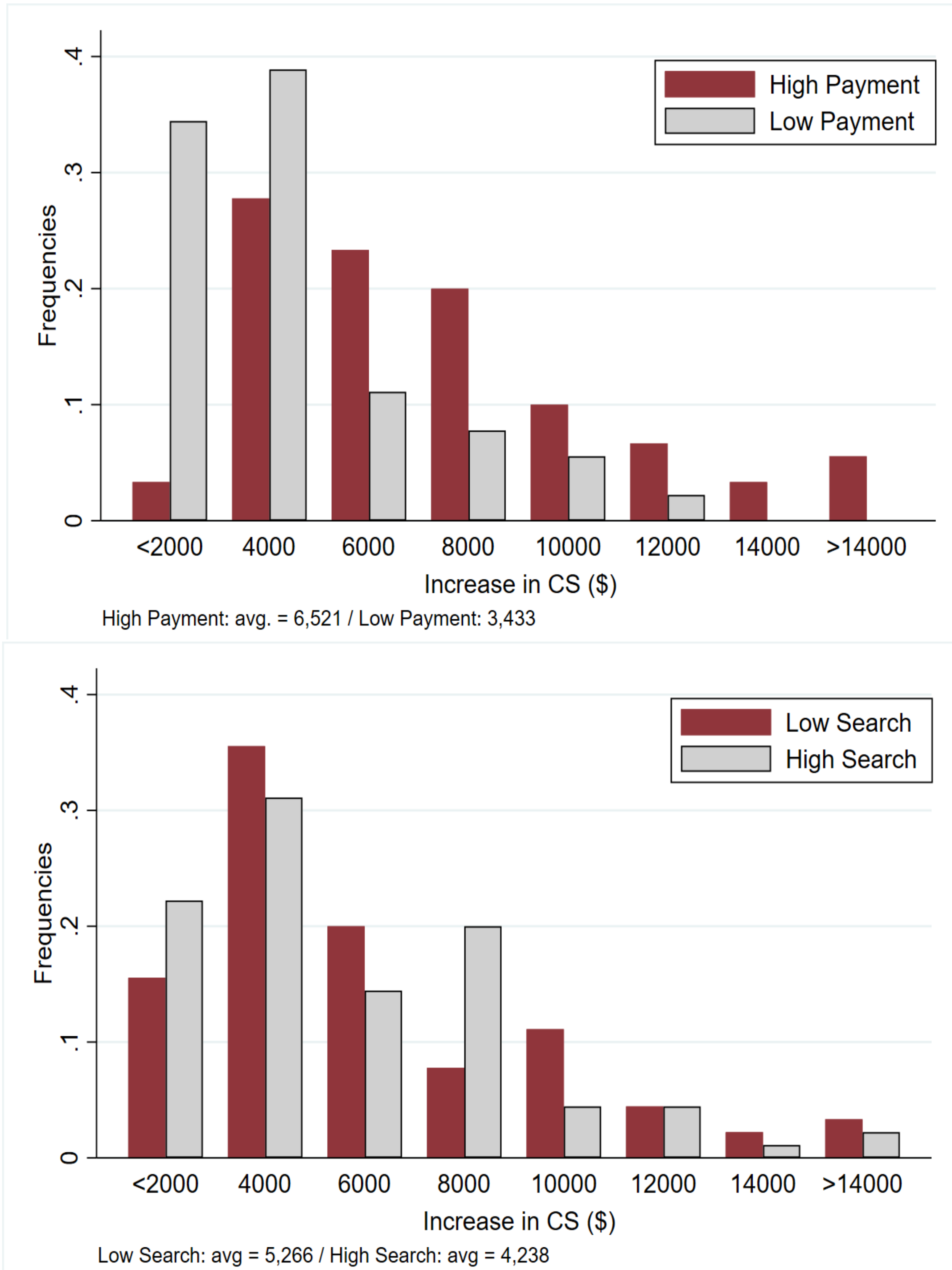


Figure 6: Distribution of Welfare Improvement

This figure plots the distribution of welfare increase if we shut down incumbent program advantage from the beginning. The top panel splits by previous mortgage payment, and the bottom split by search cost. High/Low refers to the groups that lies above/below the median.

# 8 Conclusions

In this paper, we use HARP as a case study to quantify the welfare implication associated with program design. HARP was set up with good intention—to help underwater households to refinance their mortgage. However, the design of the program unintentionally exacerbates the market power of incumbent lenders, which ends up inhibiting refinance from borrowers. It also allows the incumbent lenders to extract surplus from borrowers who decide to refinance, resulting in a lower interest rate reduction.

We develop an equilibrium model of mortgage refinancing and search decisions. We then estimate the model by exploiting a significant change to the program design that gives exogenous variation in the competitive advantage of incumbent lenders under the program. Our estimates shows that HARP gives a significant competitive advantage to incumbent lenders that makes it very hard for competing lenders to compete for households. Without this design flaw, we find that it leads to an average welfare improvement of $4,977, or 3.6% relative to the baseline. The effect is heterogeneous since the refinance market is characterized by dynamic selection: households who refinanced earlier are those with most incentives to do so. If HARP does not have the design flaw, more households could have refinanced and got a lower price from the program.

The main takeaway from our analysis is the importance of understanding institutional detail when designing policies. Whether a program will work as intended or possibly have unintended consequences depends on how the details of that policy interact with the incentives of important participants. While borrower-specific factors such as inattention and inertia may also help account for the muted response, our evidence suggests that provisions limiting the competitive advantage of incumbent lenders with respect to their existing borrowers should be an active consideration when designing stimulus polices such as HARP. This insight from this paper could also apply to other policies whose implementation depends on intermediaries with incumbent advantage with respect to targeted agents.

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## Appendix A: Program Overview

Figure 7 presents further details of HARP. The top left panel shows the average take-up rate of the program is only about 5% during its operation over 10 years, suggesting a large number of eligible households was not able to benefit from the program.[28] Second, while incumbent lenders are able to retain a market share of 28% to 33% in the traditional refinance sector (Agarwal et al. (2023)), the top right panel shows the incumbent market share is particularly high during the first half of the program. The bottom left panel shows that the people who took the program tend have relatively lower LTV, suggesting the program is not able to reach those household who need it most, i.e. those heavily underwater households. Last but not least, the bottom right panel shows big difference in interest rate reduction, suggesting heterogeneous benefit from participating the program.

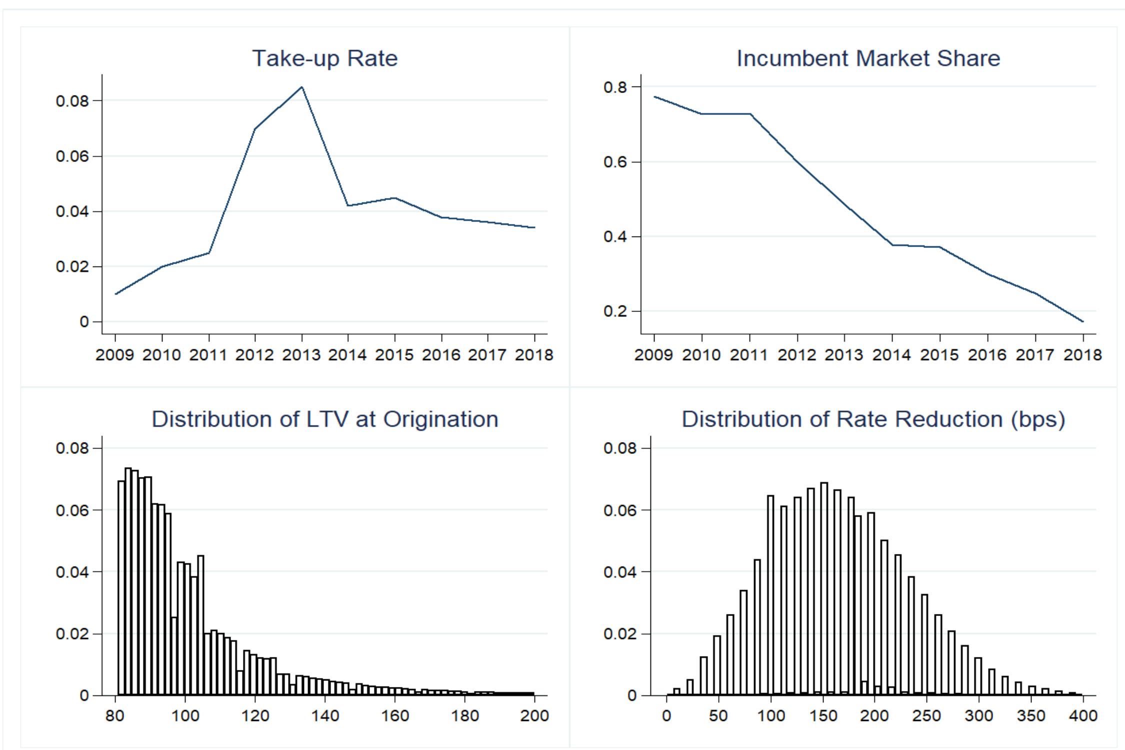


Figure 7: HARP Feature

This figure plots some features of HARP, including program take-up rate, incumbent market share, distribution of LTV at origination and distribution of interest rate reduction.

[28]We include a household as eligible if his/her LTV is above 80% according to our estimated house value using quarterly three digit zip code level house price index from FHFA.

# Appendix B: Outside Model Estimation

In Appendix B, we describe some of the parameters that we estimate directly using the data (i.e. without solving the model). These parameters include default probability (B1), expected duration (B1), idiosyncratic housing shock (B2), and put-back probability (B3).

### B1. Default and Expected Duration

In practice, people could also exit the sample because of default. Therefore, we estimate the (exogenous) probability that households will default using a loglogistic survival model. Default shock is realized before households make refinance decision at the beginning of each period. The result is presented in Column 1 of Table 5.

Since mortgage lender receives cash flow from servicing as long as the loan is still active, we specify $PV(.)$ in the profit function as the expected duration of each mortgage. We specify the expected duration as a function of observable characteristics using a log-logistic model. The result is presented in Column 2 of Table 5.

Table 5: Default and Mean Duration

| | (1) | (2) |
|---|---|---|
| | Default Probability: Log-logistic | Expected Duration: Log-logistic |
| FICO | $-0.0035$ | $-0.0010$ |
| | (-232.77) | (-272.13) |
| LTV | 1.3332 | 0.1681 |
| | (179.73) | (213.36) |
| Interest Rate | 0.4252 | $-0.6063$ |
| | (330.84) | (-318.13) |
| Balance | 0.0003 | $-0.0001$ |
| | (179.98) | (-193.32) |
| Market FE | Yes | Yes |
| Observations | 6,283,926 | 6,283,926 |

Column (1) reports the results of default probability using a log-logistic survival model, while Column (2) reports the results of expected duration using a log-logistic model. Both of them are functions of observed mortgage characteristics at origination. t-statistics is reported in parentheses. We use all available GSE refinance loan for both estimation.

## B2. Idiosyncratic Housing Shock

Given the importance of LTV in our analysis, one might worry that the mean HPI (at 3 digit zip code level) would not capture the fact that some households may persistently get below/above average housing shock, which could lead to potential measurement problem in HARP eligibility. To mitigate this concern, we use the idea from Heckman selection model to estimate the idiosyncratic housing variance.

In the first stage, we model the decision to take HARP refinance, $d_{imt}$, as:

$$d_{imt} = \alpha_0 + \alpha_1 log(HV_{im0}) + \alpha_2(log(HPI_{mt}) - log(HPI_{m0})) + \alpha_3 Z_{mt} + \alpha_4 X_{imt} + \mu_t + \mu_m + \epsilon_{imt}$$

This is the selection equation, where the dependent variable is whether a household refinanced under HARP, and the sample contains all eligible households between 2009-2015. This stage contains individual level variables ($X_i$: FICO, LTV, previous interest rate) that affect their refinance decision but should not affect the house value (exclusion restriction).

Only for those who choose to take HARP refinance in the first step, we observe their new home value at the time of refinance, denoted as $HV_{it}$ while their original home value is denoted as $HV_{i0}$. Let $m$ denote the 3-digit zip code level market that borrower $i$ is in. We estimate the following equation as the second stage:

$$\log(HV_{it}) = \beta_0 + \beta_1 \log(HV_{i0}) + \beta_3 \log(HPI_{mt}/HPI_{m0}) + \beta_4 Z_{mt} + \xi_i,\ \xi_i \sim N(0, \sigma_\xi^2)$$

where $Z_m$ is market-level controls, including local change of unemployment and income. $\xi_i$ is an unobserved individual fixed effect that determines changes in one's home value in addition to market conditions captured in $HV_{i0}, HPI_{m1}, Z_m$. This is the outcome equation where the dependent variable is the observed house price, and the sample contains all households who refinanced under HARP between 2009-2015.

The variance term, $\sigma_\xi^2$, in the outcome equation is the main parameter of interest. The result of the estimation is presented in Table 6, and the estimation suggests that there is a sizable dispersion of idiosyncratic housing shock (0.1781).

Table 6: Idiosyncratic Housing Shock

| | (1) | (2) |
|---|---|---|
| | First Stage<br>HARP Refinance | Second Stage<br>House Value |
| log(FICO) | 0.1775*** | |
| | (.0026) | |
| Prev. Rate | 0.3477*** | |
| | (.0004) | |
| Income | −0.0727*** | |
| | (.0007) | |
| log(Balance) | 0.9646*** | |
| | (.0026) | |
| log($HV_0$) | −0.3933*** | 1.0152*** |
| | (.0025) | (.0001) |
| log($\Delta HV_t$) | −1.1615*** | 0.9546*** |
| | (.0017) | (.0004) |
| %ΔUnemployment | 0.0011*** | −0.0009*** |
| | (.0000) | (.0000) |
| %ΔIncome | 0.2843*** | 0.0084*** |
| | (.0001) | (.0000) |
| $\rho$ | -0.0698 | |
| $\sigma^2$ | 0.1781 | |
| Observations | 25,434,856 | 1,022,914 |

This table report the results from a Heckman two-step selection model. The first stage is the selection equation, where the dependent variable is whether a household refinanced under HARP, and the sample contains all active households between 2009-2015. The second stage is the outcome equation where the dependent variable is the observed house price, and the sample contains all households who refinanced under HARP between 2009-2015. The main variable of interest is the variance term, $\sigma^2$, in the outcome equation.

### B3. Put-back Probability

The put-back probability is estimated using a logit regression of put-back on whether a loan is originated with the incumbent lender, conditional on all other observed characteristics as well as market and year-quarter fixed effect, using default loans from 2009-2012 and 2013-2018:

$$Putback_{itm} = \alpha + \beta X_i + \gamma Incumbent_i + \mu_t + \mu_m + \epsilon_{itm}$$

The key variable of interest is $\gamma$, and Column (1) and (2) report the result. We do find incumbent originated loan is on average 1.8% less likely to be put-back compared to the competing lenders from 2009-2012, in line with the institutional background. The coefficients from Column 2 is not statistically significant, when the rule is levelled off between incumbent and competing lenders. To rule out unobserved characteristics of selection into incumbent that could also affect default, in Column (3) we estimate a logit regression of default on incumbent (and other controls) and find the coefficient on incumbent not statistically significant.

Table 7: Logit Model of Put-back and Default

| | (1) | (2) | (3) |
|---|---|---|---|
| Sample: | Default Loans | Default Loans | All Loans |
| | 2009-2012 | 2013-2018 | 2009-2012 |
| Dep Var: | Put-back | Put-back | Default |
| Incumbent | $-0.252^{***}$ | $-0.082$ | 0.111 |
| | (0.017) | (0.092) | (0.134) |
| log(FICO) | $-2.071^{***}$ | $-1.338^{***}$ | $-6.344^{***}$ |
| | (0.349) | (0.380) | (0.062) |
| LTV | $1.303^{***}$ | $0.831^{***}$ | $1.453^{***}$ |
| | (0.276) | (0.313) | (0.036) |
| log(Balance) | $0.419^{***}$ | $0.277^{***}$ | 0.013 |
| | (0.093) | (0.105) | (0.017) |
| Prev. Rate | $0.284^{***}$ | $0.306^{***}$ | $0.296^{***}$ |
| | (0.082) | (0.091) | (0.014) |
| Market FE | Yes | Yes | Yes |
| Year-Qtr FE | Yes | Yes | Yes |
| Observations | 48,125 | 29,907 | 650,543 |
| R-squared | 0.08 | 0.05 | 0.10 |

Note: Column (1) and (2) estimate a logit regression of put-back on whether a loan is originated with the incumbent lender, conditional on all other observed characteristics as well as market and year-quarter fixed effect, using default loans from 2009-2012 and 2013-2018, respectively. To rule out unobserved characteristics of selection into incumbent that could also affect default, in Column (3) we estimate a logit regression of default on incumbent (and other controls) and find the coefficient on incumbent not statistically significant.

## Appendix C: Full Model of Competitive Offer

In Appendix C, we describe the full model of competitive offer, including the expectation of winning bid, the distribution of winning product, and each lender's winning probability. The derivation relies largely on the result from Brannman and Froeb (2000). In reality, because lenders can offer both Regular and HARP for households whose LTV is between 0.8 and 0.95, given the households also pay an upfront insurance premium. Incumbent lenders do not have the program advantage in the regular refinance. Thus, in the competitive offer, lenders need to first decide which product to bid. We assume each lender is only allowed one single bid which consists of price $r$ and product type $k$. There are 3 cases we need to consider: LTV $> 0.8$ (Regular Only), LTV $< 0.95$ (HARP Only), LTV $\in (0.8, 0.95]$ (HARP and Regular). The regular-only case follows Section 4.2.3 with symmetric costs ($\Delta = 0$, or $P_j = P_0$, $\forall j$). The HARP-only case has $\Delta > 0$ pre-2013, and $\Delta = 0$ post-2013. The last case with both HARP and Regular adds another dimension to the problem, namely the "product type", which we will now fully specify.

Before we dive into details on how lenders compete, it is necessary to specify how HARP and regular refinance are different in terms of costs. First, since HARP waived certain fees for borrowers such as appraisal fee and insurance fee, it should have a lower transaction cost than the regular refinance. Thus we assume the transaction cost are specific to product type $k$: $\phi^k, k = H, R$, with $\phi^R > \phi^H$. Second, with HARP, the incumbent has advantage in put-back cost prior to 2013: $P_j^H = P_0^H + \Delta$ for $j \neq 0$ with $\Delta > 0$. For regular refinance and post-2013 HARP, the pub-back cost is always the same regardless of lender identity: $P_j^H = P_0^H = P_0^R = P_j^R$.

When a borrower's LTV lies between $(0.8, 0.95]$, she is eligible for both HARP and regular refinance. In this case, each lender will observe two cost shocks, $\omega_j^k$, where $k = H$ (HARP refinance), or $k = R$ (regular refinance). Compared to the problem outlined in Section 4.2.3, now we can think of the lender's problem as having one more step in the beginning: choosing the right refinance type. This step can be solved by considering the following question: which refinance type gives the borrower a higher utility while delivering the same profits for the lender?

To solve this, we assume linear utility function $u(y-m,h)=y-m+h$. It follows that the borrower's utility of refinance $U(r)-\phi$, where $U$ is defined in Equation (5), is also linear in consumption. Since we are using amortized interest rate, mortgage payment $m = LoanBalance \times r$, so $U(r)$ is linear in $r$, which we assume as $U(r)=U^0-\alpha r$ with $\alpha>0$. Given $\omega_j^k$, the interest rates $r_j^k$ that makes the lender break-even is given by $M^{-1}(\omega_j^k+P_j^k)+g+c$. Plugging in borrower's utility of refinance:

$$\begin{aligned} U(r_j^k)-\phi^k = U^0-\alpha r_j^k-\phi^k &= U^0-\alpha\left[M^{-1}(\omega_j^k+P_j^k)+g+c\right]-\phi^k \\ &= U^0-\alpha\left[M^{-1}\underbrace{(\omega_j^k+P_j^k+M\alpha^{-1}\phi^k)}_{\tilde{\omega}_j^k}+g+c\right] \end{aligned}$$

Thus the refinance type that has the minimum *effective* cost shock $\tilde{\omega}_j^k \equiv \omega_j^k+P_j^k+M\alpha^{-1}\phi^k$ maximizes borrower's utility while making zero profits for the lender. This effective cost shock completely absorbs the cost differences between HARP and Regular refinances from both pub-back costs and transaction costs, thus homogenizing the two types. The level of effective cost shocks determines which type of refinance that each lender choose to bid in the auction.

Each lender chooses the minimum of HARP and Regular effective cost shock and enters the auction, defined as:

$$\tilde{\omega}_j^* = \min\{\tilde{\omega}_j^R, \tilde{\omega}_j^H\}.$$

By the property of (minimum) Gumbel distribution, $\tilde{\omega}_j^*$ has a (minimum) Gumbel distribution with the same scale $\sigma$. The mean, denoted by $\eta_j$, is given by:

$$\eta_j = E\left[\tilde{\omega}_j^*\right] = -\sigma\log\left[\sum_k \exp\left(-(P_j^k+M\alpha^{-1}\phi^k)/\sigma\right)\right]$$

The probability that lender $j$ bid type $k$ is given by

$$p_j^k \equiv \frac{\exp\left(-(P_j^k+M\alpha^{-1}\phi^k)/\sigma\right)}{\sum_{k'}\exp\left(-(P_j^{k'}+M\alpha^{-1}\phi^{k'})/\sigma\right)}$$

Note that every lender shares the same distribution of $\tilde{\omega}^*$ *except* for the incumbent prior to

2013, since the incumbent has a lower expected put-back cost. So $\eta_j$ only takes on two values, $\eta_0$ for the incumbent lender and $\eta_c$ for each competing lender. Similarly, the probability of bidding type $k$, $p_j^k$, also takes on only two values, $p_0^k$ and $p_c^k$.

Now we turn to the auction where the lender with the lowest $\tilde{\omega}_j^*$ wins. Note that the auction is essentially the same as in Section 4.2.3, with different means of effective cost shocks. It follows that the incumbent wins with probability

$$p_0^W = \frac{\exp\left(-\eta_0/\sigma\right)}{\exp\left(-\eta_0/\sigma\right) + J\exp\left(-\eta_c/\sigma\right)}$$

and every competing lender wins with probability

$$p_c^W = \frac{1}{\exp\left(-\eta_0/\sigma\right) + J\exp\left(-\eta_c/\sigma\right)}$$

Using zero-profit condition, the winning bid, $r^C$, conditional on the product type $k$ and the identity of the winner $j^*$, is given by:

$$r_k^C = M^{-1}\tilde{\omega}_{(2)}^* - \alpha^{-1}\phi^k + g + c \tag{25}$$

where $\tilde{\omega}_{(2)}^*$ is the second-lowest $\tilde{\omega}_j^*$ among all lenders. The conditional mean and distribution of $\tilde{\omega}_{(2)}^*$ given the identity of the winner $j^*$ follows Equation (16) and (18), with Equation (17) becomes

$$E\left[\tilde{\omega}_{(1)}^*|j^*\right] = -\sigma\log\left(J\cdot\exp\left(-\eta_c/\sigma\right) + \exp\left(-\eta_0/\sigma\right)\right).$$

Rewriting Equation (19), the borrower's expected value of search is

$$EU(r^C) = \sum_{j^*=0}^{J} p_{j^*}^W \sum_k p_{j^*}^k \int U\left(r_k^C(\tilde{\omega}_{(2)})\right) dF_{\tilde{\omega}_{(2)}|j^*}.$$

where we first take expectation over which lender wins, the second expectation is over which refinance type, and the last one takes conditional expectation of the winning bid given the identity of the winning lender and refinance type.

The incumbent's expected profits still follows Equation (20): $E\Pi_o^s = -\sigma\log(1-p_0^W)$.

Note that when the incumbent has lower put-back cost for HARP, it leads to higher winning probability and higher expected profits, even though regular refinance is permitted.

The incumbent's initial stage problem now also encompasses the additional dimension of refinance type. We assume that the incumbent will solve Problem (12) for each type of refinance, and choose the type that gives the higher expected profits.