Mortgage Search Heterogeneity, Statistical Discrimination and Monetary Policy Transmission to Consumption*

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Abstract

In the US, half of all mortgage borrowers consider only one lender when refinancing. We investigate how statistical discrimination by lenders, a tool that separates borrowers who differ in search intensity, affects welfare and monetary policy transmission to consumption. We build and calibrate a general equilibrium model of the mortgage market with two types of borrowers who differ in the number of lenders they meet. Statistical discrimination based on the relative mass of the two types at any observable current mortgage rate and home equity level results in relatively higher offer rates for non-shoppers. Higher offer rates reduce the incentive to refinance. Repeated refinancing increases the separation between the two types, reinforcing the mechanism. Statistical discrimination carries a significant welfare cost ($3,300) for a borrower, accounting for two-thirds of the total difference in welfare between the two types. Two ways of increasing mortgage search, an explicit goal of the CFPB, have opposite effects on welfare. If every third non-shopper meets one more lender, the welfare cost becomes two-thirds. However, this cost quadruples if, instead, every shopper meets one more lender. Statistical discrimination halves non-shoppers' consumption response to a monetary policy shock but does not increase shoppers' response. Thus, it reduces aggregate consumption response by a third. Hence, the subtle ability to statistically discriminate is highly relevant for policymaking.

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1 Introduction

According to the National Survey of Mortgage Originations (NSMO), 52% of US homeowners consider only one lender when refinancing their mortgage. We refer to them as non-shoppers. In the data described below, we find that non-shoppers pay higher rates. Two possible explanations exist. First, non-shoppers will see only one offered rate, leading to higher accepted rates - a direct effect of reduced search. Second, lenders may use available information to statistically discriminate - a less intuitive indirect effect. Lenders can observe the current mortgage of a refinancer. If they know how many shoppers and how many non-shoppers hold the same mortgage, they can evaluate the probability that the refinancer will not search for another quote. The higher this probability, the higher the rate that lenders offer. A higher offer rate also reduces the incentive to refinance. With repeated refinancing, the difference in rates between shoppers and non-shoppers would continue to increase, making it easier to statistically discriminate.

In this environment, we ask the following questions. First, what is the welfare cost of statistical discrimination to a borrower? How does this cost change if either one-third of non-shoppers or all shoppers search for one more quote? Both increase mortgage search, an explicit aim of the Consumer Financial Protection Bureau (CFPB), but in different ways. Second, how does variation in the ability to statistically discriminate change monetary policy transmission to consumption? Consuming the home equity extracted via mortgage refinancing has been found to be an important channel for this transmission.

To answer these questions, we build a general equilibrium model with two types of mortgage borrowers. The first type, the non-shoppers, consider an offer from only one lender. The second type, the shoppers, consider offers from two lenders. A borrower who refinances meets a random subset of identical lenders simultaneously before getting any offer. Short-lived lenders do not know the type of the borrower they meet but they observe her state (current rate and mortgage balance) and know the mass of each type in any state. This enables them to statistically discriminate. In any state, the refinancing market is similar to the product market in Burdett and Judd (1983), which leads to rate dispersion among identical borrowers. The production side of the economy consists of standard New-Keynesian firms. This allows the monetary authority's nominal changes to have significant real changes.

We calibrate the parameters governing search cost and the fraction of borrowers who are shoppers to match the average years to refinance a mortgage according to the Freddie Mac and Fannie Mae's Single Family Loan-Level Dataset (GSE) and the fraction of refinancers who are shoppers according to the NSMO, while other parameters are chosen from the literature. To answer the first question, the following is done. Comparing borrower welfare in the benchmark economy with that in a counterfactual economy where their current state is unobservable (thus removing the ability to statistically discriminate) allows us to evaluate the welfare cost of statistical distribution. Repeating this by changing the benchmark economy to a counterfactual economy where one-third of non-shoppers consider offers from two lenders and to another counterfactual economy where shoppers consider offers from three lenders answers how the welfare cost changes with these two ways of increasing mortgage search. To answer the second question, we look at how agents in the steady states of the benchmark and the three counterfactual economies respond to an expansionary monetary policy shock: an unexpected 25 basis points reduction in the nominal risk-free rate, which is also the cost of lending in the model.

We conclude that statistical discrimination has a large welfare cost based on three steady state results. First, a borrower is willing to pay about $3,300 (30% of quarterly income) to make her current state unobservable and thus remove lenders' ability to statistically discriminate. Non-shoppers are willing to pay much more ($5,700). This cost is small when they first purchase a home, but quadruples within eight years due to the increasing isolation of non-shoppers at high rates with each round of refinancing. On the other hand, shoppers are not isolated at low rates because in equilibrium, many lenders post low rates (Pareto distribution) which non-shoppers can also get; moreover, with repeated refinancing, many non-shoppers eventually end up with low rates. Therefore, shoppers do not benefit much from statistical discrimination. Thus, the ability to statistically discriminate causes a large shift in welfare from borrowers to lenders. In the data, the rate distribution is significantly left-skewed (close to Pareto), which validates this result. Also, in steady state, the time after which a borrower refinances again is U-shaped in her state. Non-shoppers who are isolated at high rates wait and collect home equity before refinancing again, borrowers who get lower rates refinance sooner as there are more shoppers with the same rates and thus the rate reduction offered is higher, and once borrowers get low enough rates, they do not refinance again. This U-shaped relation is also observed in the data, validating the mechanism.

Second, statistical discrimination accounts for two-thirds of the difference in welfare between the two types. A non-shopper is willing to pay $7,700 to become a shopper. This declines to $2,300 if the current state is unobservable. Third, the two ways of increasing mortgage search change the ability to statistically discriminate (and thus the associated welfare cost) in opposite directions. If one-third of non-shoppers consider two lenders, the welfare cost becomes two-thirds ($2,100) of that in the benchmark; but if shoppers consider three lenders, the welfare cost quadruples ($13,800). If shoppers consider three lenders, the increased isolation benefits shoppers - they have a negative welfare cost (-$220) and statistical discrimination now accounts for three-fourths of the difference in welfare between the two types.

We find that statistical discrimination reduces the monetary policy transmission to consumption, especially by reducing the refinancing response of non-shoppers. There is hardly any pass-through of rate reduction to non-shoppers who are isolated at high rates. Thus, few of them refinance in response to a monetary policy shock. Even when they do, they extract much smaller home equity they collect in steady state compared to shoppers. Hence, non-shoppers have a smaller consumption response.

In the two counterfactual economies that have higher mortgage search levels than the benchmark economy, the consumption response of non-shoppers changes in opposite directions. Presented in the order of increasing ability to statistically discriminate, the four economies are as follows: unobservable current state, one-third of non-shoppers consider two lenders, benchmark, and shoppers consider three lenders. In these four economies, a non-shopper's consumption increases by 1.21%, 0.93%, 0.57% and 0.31% respectively in response to the monetary shock mentioned above.

In contrast, shoppers have a bigger consumption response than non-shoppers in all economies except the one with unobservable current state, since they collect more home equity in steady state as a result of getting lower rates sooner. In the counterfactual economy with unobservable current state, both types have very similar home equity in steady state but non-shoppers have slightly higher rates due to their lack of search. Without statistical discrimination, non-shoppers obtain a much larger rate reduction and thus they respond much more than non-shoppers in the benchmark. For shoppers, there is not much change in isolation across the four economies. In the counterfactual economies with higher mortgage search levels, the aggregate reduction in market power of lenders results in more home equity and thus in a greater consumption response among shoppers than in the benchmark economy. A shopper's consumption increases by 0.88%, 1.15%, 0.84% and 0.92% respectively in response to the same shock in the four economies mentioned earlier. Thus, statistical discrimination changes monetary policy transmission to consumption at the aggregate level as well as at the distributional level.

Consistent with the model, our empirical findings imply that otherwise identical mortgage borrowers who refinance with different unobservable search intensities get very different rates and borrow very different amounts. There is a wide range of mortgage rates (standard deviation of 26 basis points) that a refinancer gets after controlling for risk factors, lender, location, and month of origination from the GSE data. Discount points, weekly variation, and a proxy for unobserved credit risk explain only a small part of this variation. In the NSMO, non-shoppers borrow $2,750 less and pay 8 basis points more than shoppers. This difference in rates falls to 3 basis points in the mortgage market for home purchases, where there is no current mortgage that lenders can use to statistically discriminate. It is difficult to identify whether a borrower will consider one or more than one lender: a probit classifier with more than

80 borrower characteristics is unable to classify 37% borrowers correctly. We use the Home Mortgage Disclosure Act Loan Application Register (HMDA LAR) to find that even before NSMO started in 2013, MSAs with above median mortgage search activity in a year had average mortgage rates that were 6 basis points lower than those of MSAs with search levels below the median, and home equity extraction rates that were 7.5% higher. Consistent with the relationship between a borrower's state and the time after which she refinances in the model, we find in the GSE data that the number of months after origination at which borrowers refinance is U-shaped in the product of their current mortgage rate and balance. Without targeting, the distribution of borrowers in steady state matches that observed in the data at the end of 2015 when the cost of mortgage lending was relatively stable, supporting our model's assumptions and results.

In our related work, Ambokar and Samaee (2019), we empirically explore the role of search costs in explaining inaction in refinancing. Hence, we estimate the search cost distribution of mortgage borrowers in the US and find that search costs, and not creditworthiness, inhibit mortgage refinancing mainly due to the resulting increase in market power of lenders. Here, the focus is on understanding the effects of the subtle mechanism of statistical discrimination. Hence, we enable lenders to statistically discriminate and find that this mechanism has a large impact on welfare and significantly affects monetary policy transmission. In both papers, we find that lenders' actions play a huge role in determining borrowers' actions and thus in determining the outcomes in the US mortgage market.

We show that considering mortgage search heterogeneity and statistical discrimination in a dynamic general equilibrium framework is important to understanding agents' decisions in the US mortgage market and their aggregate effects. This subtle mechanism also affects the distribution of home equity studied in Beraja et. al. (2018). Dispersion in rates affect the potential savings studied in Eichenbaum et. al. (2018). As in Wong (2019), younger borrowers are more likely to refinance than older ones. Chen et. al. (2018) consider labor income risk heterogeneity and Greenwald (2018) considers payment-to-income restrictions, which are left for future work. In empirical work, Woodward and Hall (2012) first documented the substantial price dispersion in mortgage markets. Agarwal et. al. (2017) find that search costs and creditworthiness together explain mortgage search behavior whereas our focus in the other paper is on inaction in refinancing. Alexandrov and Koulayev (2017) document price dispersion in reference rates; we use contracted rates. Bhutta et. al. (2018) find a wide dispersion in rates even after controlling for discount points, which are not available in our data. Hurst et. al. (2016) find that there is no spatial variation in GSE mortgage rates, which we confirm. Our estimate of the lost savings due to lack of mortgage search is in line with that in Keys et. al. (2016). Allen et. al. (2014) find that competition does not benefit those with high rates. This is similar to the outcome of non-shoppers isolated at high rates in our model.

2 Data and Analysis

We use multiple data sources to analyze different issues that motivate this study and become the targets for the model built in the later section. We find that there is a wide spread in the mortgage rates that borrowers get after controlling for their observable as well as unobservable risk factors, lenders, location and time using Freddie Mac and Fannie Mae's Single Family Loan-Level Dataset. Using the performance data of the loans in this dataset, we find that the refinance behavior of borrowers with respect to their mortgage rate and mortgage balance is consistent with that in the model. We find that borrowers search for their mortgage differently and their outcomes are significantly different conditional on their search behavior using the National Survey of Mortgage Originations dataset. Finally, since the survey data date backs to only 2013, we use the Home Mortgage Disclosure Act (HMDA) Loan Application Register data to see how search behavior and outcomes for the borrowers relate before 2013, but at an aggregate level, and find similar results. Below we describe our empirical results in detail.

2.1 Freddie Mac and Fannie Mae Loans Data

We use the single-family mortgage originations and their performance public dataset from Freddie Mac and Fannie Mae for the period 1999 to 2016. This dataset has about 65% of the mortgages originated in the US during this period. It does not record the search behavior of borrowers. It has over 60 million mortgage originations over this period. This dataset allows us to determine whether lenders offer different rates to observationally equivalent borrowers and the refinance behavior of borrowers with respect to their mortgage rate and mortgage balance.

To focus on how the mortgage rate varies within a particular homogenous type of mortgage, we first restrict the sample to the mortgages originated at fixed rate for 30 years, property is single-family owner-occupied, one-unit, without any prepayment penalty, with no insurance and not super-conforming for borrowers with FICO score at least 660. This product is highly prevalent in the sample and generates a subsample of over 19 million mortgages over the 18 year period. The refinance behavior is also analyzed using this subsample.

2.1.1 Rate dispersion

The GSEs set fees every month for this mortgage product that vary by FICO score, LTV and loan type only. As we restrict the sample to 30 year fixed-rate fully documented mortgages, the only two dimensions of credit quality that should materially affect rates on GSE-guaranteed mortgages in any month are FICO and LTV. So, we follow the procedure used in Hurst et. al. (2016) to obtain residual mortgage rates after controlling for borrower characteristics and time fixed effects. In particular, we run:

$$r_{it}^{j} = \alpha_0^j + \alpha_1^j D_t + \alpha_2^j X_{it} + \alpha_3^j D_t X_{it} + \alpha_4^j Z_{it} + \varepsilon_{it}^j$$

where r_{it}^{j} is the loan-level mortgage rate for a loan made to borrower i during month of origination t, D_t is a vector of time dummies based on the month of origination, X_{it} is a series of FICO dummies (660-679, 680-699, ... 780-799, etc.) and a series of LTV dummies (50-54, 55-59, ...80-84, ...95-99, etc.) for borrower i in period t and Z_{it} is the vector (purpose of mortgage, mortgage amount, debt-to-income ratio, cumulative LTV, channel of origination, whether first home, number of borrowers on the mortgage, originator, 3-digit zip code of the property) . Sample j refers to whether the mortgage was purchased by Freddie Mac or Fannie Mae. We run these regressions separately using data from each of our two GSE datasets. The results are summarized in Table 1. 92.58% and 94.48% of the variation in interest rates in the two samples is explained by this regression. Combining the errors in prediction from both the samples, the unexplained variance in rates has a standard deviation of 26.67 basis points. Some of this variation is because of weekly variation in rates and discount points bought by borrowers but Bhutta et. al. (2018) find that discount points account for about 15 basis points variation and weekly variation in rates within a month are on average less than 10 basis points. We also check how much of this variation is due to credit risk not observed in the data but observable to the lender via additional documents like the full credit report. Such additional information might predict payment delinquency and eventually default in the future. Hence, as a proxy for this unobserved information, we add the ex-post information about payment delinquency: the maximum number of months that the borrower has been delinquent in the first four years since origination to the vector Z_{it} in the above model. This information is found in the Performance data of these mortgages. We do not consider mortgages originated in the last four years of the sample to remove any bias. The maximum delinquency value is 0 for 90.66% of the borrowers and at least 6 for 1.23% of the borrowers in this sample. We compare the result of this model to the baseline model with the same sample size. We find that there is hardly any reduction in the standard deviation of the unexplained variance. Hence, we conclude that the unexplained variance is

Dependent Variable: Mortgage Rate	Data: Freddie Mac				Data: Fannie Mae			
Sample from 1999 to:	2016	2016	2012	2012	2016	2016	2012	2012
Origination Month	Y	Y	Y	Y	Y	Y	Y	Y
FICO, LTV dummies	Y	Y	Y	Y	Y	Y	Y	Y
Other variables at origination (Z_{it})	Y	Y	Y	Y	Y	Y	Y	Y
Max. delinquency in first 4 years	N	N	N	Y	N	N	N	Y
Refinances only?	N	Y	N	N	N	Y	N	N
Adjusted R^2	.9258	.9537	.8944	.8950	.9448	.9572	.9083	.9084
Observations	5800608	2618597	5304385	5293178	10491098	3061929	8261540	8260949
RMSE	.2651	.2521	.2706	.2699	.2677	.2591	.2759	.2758

Table 1: Unexplained mortgage rate has a wide dispersion (RMSE). The dispersion does not decrease much by adding a proxy for unobserved risk (Max. delinquency in first 4 years) or by looking only at refinances.

not due to unobserved credit risk. Thus, most of the variation found here, about four times 26.67 basis points, remains unaccounted. We repeat this exercise for only refinance mortgages which are 70% of the sample as our focus is on refinances and find that there is hardly any change in results (standard deviation reduces from 26.67 to 25.59 basis points). Hence, the annual mortgage payment of two observationally equivalent borrowers in the same area, month of origination and mortgage lender whose mortgage rate differs by one standard deviation would differ by about $360 on a mortgage of $200,000. Hence, there is a substantial amount of saving for the borrower if she shops harder for the mortgage.

2.1.2 Refinance Behavior

To verify whether the novel finding from the model in Section 4.1 is observed in the data, we analyze how the refinance behavior of borrowers varies with respect to their mortgage rate and mortgage balance. In particular, we find that the refinancing decision of borrowers is not a simple threshold rule but is non-monotonic in their current mortgage rate and mortgage balance. In the model, this is a result of the relative intensity of mortgage search in each submarket characterized by the current mortgage rate and mortgage balance. Hence, in the data, we build a variable which is the product of the current mortgage rate and current mortgage balance divided by 100,000; let us label it 'state' and see how it affects the variable 'loan age': months after origination at which the loan has been refinanced. If the novel finding in the model is also observable in data, loan age should decrease and then increase in the range of the state variable, which we find is the case using the following regression:

$$LoanAge_i = \alpha + \beta_1 State_i + \beta_2 State_i^2 + \kappa X_i + \delta D_i + \varepsilon_{it}$$

where the individual borrower i refinances their mortgage in month D_i and had the characteristics X_i (FICO score, LTV, cumulative LTV, debt-to-income ratio, whether first home, number of borrowers on the mortgage) at origination. Mortgages originated before 2011 were considered for this regression so that recency does not impact the results. The results of this regression are stated in Table 4. The state variable in the data ranges between a minimum of 0 and a maximum of 59 (1 percentile: 1.277, 99 percentile: 27.435) in which loan age is decreasing then increasing in the state variable based on the coefficients in the regression. Thus, the novel finding in the model is observed in the data as well, validating the main mechanism in the model.

2.2 National Survey of Mortgage Originations

The National Survey of Mortgage Originations (NSMO) conducted since 2013 by the Consumer Finance Protection Bureau (CFPB) and the Federal Housing Finance Agency (FHFA) allows us to look at individual-level search behavior in the mortgage market. It has about 6,000 respondents per year and a total of 24,640 observations in the sample considered. We investigate this search behavior. We check how well can borrower characteristics help identify their search behavior and what are the outcomes for borrowers with different search behavior in terms of the rates and mortgage size they get.

2.2.1 Search Behavior

The survey reveals that half of all borrowers seriously considered only one lender and nearly 80% of them applied to only one lender. A third of the borrowers chose a lender based on past relationships, reputation and having a local branch. Figure 13 reveals the percentage of mortgage borrowers (on left) and refinancers (on right) who seriously considered 1, 2, 3, 4, 5 or more lenders in the entire sample from 2013 onwards.

2.2.2 Identifying who go to only one lender

To see whether borrower characteristics can help explain their search behavior, we build a dummy variable of whether the mortgage borrower seriously considered one lender or more than one lender. We use more than 80 characteristics of that mortgage like the month of origination, PMMS rate in that month, loan amount category, FICO, LTV, CLTV, DTI, PTI, first homebuyer flag, number of borrowers, whether

	rate	amount	rate	rate
More than 1 lender considered	-0.050***	0.057*	-0.079***	-0.028*
Purpose	Any	Any	Refinance	Purchase
Adjusted R^2	0.355	0.564	0.396	0.32
Observations	8497	8497	3768	4476

***: p-value < 0.01, *: p-value < 0.1

Table 2: Those who consider only one lender get higher rate & lower amount. The difference in rate is much bigger for refinancers than for home purchasers, an indication of the effect of statistical discrimination in the refinance market that is absent in home purchasers market (NSMO)

property is in a metro, age, education, race, income, financial awareness as explanatory variables in a probit model to see whether these variables help predict the dummy variable created. We find that the model classifies 63.42% of the borrowers correctly which is a minor improvement over a random classifier which could classify about 50% correctly.

2.2.3 Outcomes for those who go to only one lender

We find that those who consider one lender borrow about $2850 less at about 5 basis points higher rate on average compared to those who consider more than one. This difference is such that the mortgage payment across these borrowers remains the same. Interestingly, for refinancers, the difference increases to 8 basis points compared to 3 basis points for home purchases. This is indicative evidence of statistical discrimination between those who look for multiple lenders versus those who look for one. It is prevalent in the refinance market but not in purchase market in which half of purchasers are first-homebuyers for whom there is no history of mortgage search which is necessary for statistical discrimination studied in this paper.

To find these results, we run regressions to explain the mortgage rate and the loan amount with the dummy variable built earlier and use the more than 80 characteristics of the mortgage mentioned above as controls. We restrict the sample to 30 year fixed rate, conforming, non-jumbo agency mortgages for these regressions. The results are summarized in Table 2. Note that the loan amount is a category variable with $50,000 interval dummies.

2.3 HMDA Loan Applications Register

Since the NSMO only tells us about the search behavior of borrowers from 2013 onwards, we look at the Home Mortgage Disclosure Act (HMDA) Loan Application Register public data to see how mortgage search activity affected outcomes similar to those mentioned above for the borrowers. HMDA data has loan applications since 1981 for 90% of the US mortgage market. But the public data does not allow us to identify the borrower and thus we cannot get individual search behavior as in the NSMO.

To overcome this, we build a measure of search activity in a MSA in a year which is defined as the number of applications withdrawn by the borrower or approved by the lender but declined by the borrower divided by the number of applications approved and accepted. We compare how this search activity relates to the home equity extraction rate and the average mortgage rate spread observed in that MSA and year. In particular, using the Freddie Mac and Fannie Mae data, we build a MSA-year wise variable of mortgage amount originated for home equity extraction divided by the total mortgage amount originated and a MSA-year wise average spread between the mortgage rate and the current coupon rate of a 30 year fixed rate agency MBS in the month of origination which is defined as the secondary market rate in Fuster et. al. (2013). This secondary market rate is the cost of mortgage lending. We find that it is tightly connected to the effective federal funds rate which is influenced by Federal Reserve's open market operations. Hence, in the model, we will set the cost of lending to be equal to the nominal risk-free interest rate in the economy. Figure 14 shows these rates and the primary mortgage market survey (PMMS) rate since 1994 and Table 5 shows the results of regressing the primary and secondary mortgage market rates on the effective federal funds rate.

2.3.1 Areas with More Search respond more to a Rate reduction

Even before 2013, higher search is related to lower rates and more home equity extraction. The top panel of Figure 15 shows how search activity and home equity extraction move together across years and that within a year, in MSAs with above median search activity, home equity extraction has been consistently higher. The bottom panel of Figure 15 shows that across years, a change in search activity has coincided with an opposing change in the average rate spread and that within a year, across MSAs, above median search MSAs have seen a slightly lower rate spread compared to below median search MSAs.

We formally find this relation in the regression below where the dependent variable H_{imt} is the home equity extracted by an individual normalized by the total amount borrowed in MSA m and month t. Explanatory variables are P_t, the primary mortgage market survey (PMMS) rate in that month, search activity in that MSA-year S_{my}, their interaction term and controls X_{imt}, FICO, LTV, CLTV, DTI, channel, number of borrowers on the mortgage, lender, month and MSA. In particular,

$$H_{imt} = \alpha_0 + \alpha_1 P_t + \alpha_2 S_{my} + \alpha_3 P_t S_{my} + \alpha_4 X_{imt} + \varepsilon_{imt}$$

The results of the regression are summarized in Table 6.

Based on this regression, we find that a one standard deviation fall in the PMMS rate results in a rise in the home equity extraction by 6.51% of the standard deviation in a MSA-year with average search activity. But in a MSA-year with 1 standard deviation higher search activity, this response is 8.95% of the standard deviation. Thus, a higher search activity area responds 37% more to a rate reduction than a lower search activity area in terms of home equity extraction.

3 Model

Our empirical findings become the basis of our main assumptions in the model and also the targets for our model[1]. There are two exogenous types of borrowers: those who meet 1 lender and those who meet 2 lenders at refinancing by paying the same fixed cost. Their search behavior is unobservable to short-lived banks (lenders who take deposits; I will use the terms lenders and banks interchangeably). We focus on the refinance market where statistical discrimination and monetary policy transmission to consumption is more relevant. Hence, the model does not have home purchase and mortgage origination decisions. The home size and price are also constants. The refinance mortgage is similar to the product in Burdett and Judd (1983) where a refinancer's heterogeneous non-sequential random search for identical lenders leads to price dispersion for the product. Standard New-Keynesian firms allow changes in nominal interest rates made by a monetary authority to result in significant changes in real quantities like consumption. Below is the complete description of the model.

[1] Apart from price dispersion and heterogeneous mortgage search detailed in Section 2, it typically takes 1-2 months to get an offer after application during which time another application made would be equivalent to a non-sequential search; According to NSMO, refinancers initiate contact 73% of times; Multiple applications made by refinancer within 45 days shows up as one application in a credit report, thus lenders cannot observe their search behavior in that period; Lenders profit most in the first period by selling to the GSE's, hence short-lived. Average years to refinance a GSE loan and fraction of refinancers who seriously consider more than one lender in the NSMO survey are used to calibrate two parameters: search cost and fraction of borrowers who meet multiple lenders. Exogenous heterogeneity in search behavior, instead of search cost, also results in a tight match with untargeted distribution in the data.

3.1 Environment

The model has discrete and infinite time indexed by $t = 0, 1, 2, ...$ It has households who are born with a mortgage and make refinancing decisions and lenders who set mortgage rates to maximize their profits. Each agent is described below.

3.1.1 Households

Household Types There is a unit continuum of households who are either borrowers or savers. Each borrower is exogenously either a Type 1 or a Type 2 borrower. A Type 1 borrower meets only one lender at refinancing whereas a Type 2 borrower meets two lenders non-sequentially at refinancing.

Borrowers are more impatient than savers based on their respective rate of discounting the future, i.e., borrowers' β_b is less than savers' β_s which are both less than 1. Each agent survives a period with probability $\zeta < 1$ and is replaced by the same types. So, the effective rate of discounting of a household $i \in \{b, s\}$ is $\beta_i^{eff} = \zeta \beta_s$.

In any period, there is a fixed mass $\chi_s < 1$ of savers and $(1 - \chi_s)$ of borrowers. Out of the borrowers, $\alpha(1 - \chi_s)$ are Type 2 borrowers and the rest $(1 - \alpha)(1 - \chi_s)$ are Type 1 borrowers.

Household Commonalities The period utility of a household $i \in \{b, s\}$ is given by:

$$u^i_{a,\hat{\eta}}(c,l) = log(c) + \xi log(h) - \psi_i \frac{l^{1+\phi}}{1+\phi} - \hat{\eta}\{a = \mathscr{R}\}$$

where $a \in \{\mathscr{R}, \mathscr{N}\}$ is the action taken by the household in that period: whether to refinance ($\mathscr{R}$) or not to refinance ($\mathscr{N}$), $\hat{\eta}$ is the utility cost of refinancing, ψ_i is the household-type specific parameter for disutility of labor l, ξ is the utility of housing h relative to the utility from consumption c and ϕ is the inverse Frisch elasticity. Note that both type of borrowers pay the same utility cost of refinancing but Type 1 meet only one lender whereas Type 2 meet two lenders. Each period, with probability λ, a household receives a shock by which the cost of refinancing disappears; otherwise, it is equal to a constant η. Thus,

$$\hat{\eta} = \begin{cases} \eta & with\ prob.\ 1-\lambda \\ 0 & with\ prob.\ \lambda \end{cases}$$

Moreover, each household is born with a house of price p and size h which are both constants. Each household pays a maintenance cost of δph for the house. Each household is endowed with one unit of labor per period.

Household Differences Borrowers are born with a long-term mortgage of fixed size m_0 at a fixed rate r_0. They pay down $\nu < 1$ fraction of the principal and the interest on the mortgage each period. Each borrower can choose to refinance each period. On the other hand, savers own their homes mortgage-free and they own the firms and the banks in the economy. They have access to one-period nominal bonds and bank deposits.

3.1.2 Banks

Banks cannot observe the type or the refinancing cost of a refinancer that meets them. There are a large number B of banks. They observe the mortgage balance m and the current mortgage rate r of the refinancer. Each bank is short-lived across two periods. In their first period, a bank gets deposits d from savers at a promised risk-free rate i, lends m' to each refinancer by offering rate r' and gets non-refinanced mortgages at cost from a bank in its second period. In their second period, a bank gets a payment $m'(1+r')$ from each borrower, transfers the non-refinanced mortgages at cost to banks in their first period and returns deposits $d(1+i)$ and profits $m'(r'-i)$ from each borrower to savers.

Since the banks are short-lived, their profit maximization at origination of a mortgage considers only the profit at the time of origination. This reflects the institutional behavior in the agency mortgage market in the US, where the lending banks originate to sell immediately to the agencies Fannie Mae and Freddie Mac and thus most of their profit is received at origination of the mortgage. We do not model the agencies explicitly but having risk-neutral competitive agencies would result in the short-term risk-free rate being the cost of funding for the banks, as we have in our model.

3.1.3 Firms

Firms are standard New-Keynesian to introduce rigidities in the model in order to have real aggregate impact of nominal changes. There is a competitive final good producer who purchases inputs from a unit continuum of intermediate goods producers who set the price of their intermediate good but a fraction Ψ

of them are unable to update their price. The intermediate good producer uses labor in a linear production function to produce their goods.

3.1.4 Monetary Authority

The monetary authority sets the nominal risk-free interest rate in the economy according to a Taylor-type interest rate rule as in Iacoviello (2005).

3.2 Decision Problems

The decision problems of the agents described above are stated below.

3.2.1 Borrowers

Individual-specific states of a borrower are its Type j, $j \in \{1,2\}$, current mortgage balance m, current interest rate r and the realization of the cost of refinancing $\hat{\eta}$. Let $\mu(j,m,r)$ be the mass of Type j borrowers, $j \in \{1,2\}$ whose current mortgage balance is m and current interest rate is r. Note that we did not include $\hat{\eta}$ to define the mass since $\mu(j,m,r)$ is a sufficient to know that out of these, $\lambda\mu(j,m,r)$ have no cost of refinancing. Hence, let $\mu := \{\mu(j,m,r)\}_{j,m,r}$ be the distribution of borrowers over the entire state space. This distribution denotes the aggregate state of the economy and inflation and wage rate are its functions.

We define $\mathbb{S} := \{\hat{\eta}, j, m, r; \mu\}$ as the current state of a borrower before she decides whether to refinance. A bank cannot observe $\hat{\eta}$ and j. The shock to the cost of refinancing ensures that there are refinancers of each type for every m, r in which they are present. As known from Burdett and Judd (1983), due to heterogeneity in search, there is no pure strategy solution for a bank. So, let $F(r', \mathbb{K})$ be the proportion of identical banks who post no greater than r' when they meet a refinancer with mortgage balance m and rate r, where $\mathbb{K} := \{m, r; \mu\}$ and r' cannot exceed r.

Thus, the decision problem of a borrower is:

$$V(\mathbb{S}) = max\{V_{\mathscr{N}}(r, \mathbb{S}),\ E_{r'|\mathbb{S}} V_{\mathscr{R}}(r', \mathbb{S})\}$$

A borrower chooses whether to refinance ($\mathscr{R}$) or not to refinance ($\mathscr{N}$) based on which choice maximizes their expected lifetime value. Note that they decide to refinance first and then meet one or two banks based on their type. Type 1 meets one lender from the distribution of lenders $F(r', \mathbb{K})$ whereas Type 2 meets two of them non-sequentially and chooses the minimum of the two rates that they offer, the effective distribution of lenders that they meet depends on their type as below:

$$r'|\mathbb{S} \sim \begin{cases} dF(r', \mathbb{K}) & j = 1 \\ 2(1 - F(r', \mathbb{K}))dF(r', \mathbb{K}) & j = 2 \end{cases}$$

Conditional on their action $a \in \{\mathscr{R}, \mathscr{N}\}$, households choose consumption c and labor effort l maximize their lifetime utility. Their decision problem now is:

$$V_a(r', \mathbb{S}) = \max_{c,l} u^b_{a,\hat{\eta}}(c, l) + \beta^{eff}_b V(\mathbb{S}')$$

where $u^b_{a,\hat{\eta}}(c, l)$ is the period utility mentioned above and they face the budget constraint:

$$c + \pi(\mu)^{-1}(m(r + \nu) + m(1 - \nu)) + \delta ph = m' + w(\mu)l$$

where $\pi(\mu)$ is the gross inflation and $w(\mu)$ is the wage rate in the economy, mr is the nominal interest payment and $m\nu$ is the nominal principal payment on the mortgage, $m(1 - \nu)$ is the remaining nominal principal on the mortgage, δph is the maintenance on the house and the new balance on the mortgage depends on the decision to refinance or not as below:

$$m' = \begin{cases} \theta^{LTV} ph & a = \mathscr{R} \\ \pi(\mu)^{-1} m(1 - \nu) & a = \mathscr{N} \end{cases}$$

where θ^{LTV} is a parameter that defines the maximum ratio of the mortgage amount to the value of the home that a borrower can borrow. Thus, borrowers always refinance up to their LTV limit. This assumption simplifies the household problem and the computations in the model. It has been used commonly in the literature and has been shown to have little effect on the conclusions of the model since even without this restriction, most borrowers borrow up to their borrowing limit (e.g., Beraja et. al. (2018), Greenwald (2018)). If they do not refinance, they continue with the remaining principal amount on their mortgage. Finally, the maximum labor effort is normalized to 1, the function H defines the law of motion of the aggregate state and the type of the borrower is persistent:

$$l \leq 1,\ \mu' = H(\mu),\ j' = j$$

3.2.2 Banks

For each mortgage balance m and current rate r, a bank post rates for the refinancers with that (m, r) to maximize their profit. They do not observe the type of the borrower and hence only infer the probability of the borrower being either Type 1 or Type 2 based on the mass of borrowers in that state, and their optimal decisions in that state with and without the refinancing cost shock. In addition to that, they receive the regular mortgage payments from the non-refinancing borrowers in that submarket. Thus, a bank's profit maximization problem is:

$$\begin{aligned}\mathscr{P}(\mu) = \int\int \frac{1}{B}\{&\pi(\mu)^{-1}m(1-\nu)(r-i)\sum_{j=1}^{2} q_{\mathscr{N}}(j,\mathbb{K}) \\ &+ \max_{r'}(\theta^{LTV} ph(r'-i)(q_{\mathscr{R}}(1,\mathbb{K}) + 2(1-F(r',\mathbb{K}))q_{\mathscr{R}}(2,\mathbb{K})))\}dmdr \qquad (1)\end{aligned}$$

where the mass of refinancers $q_{\mathscr{R}}(j,\mathbb{K})$ is the fraction of mass of that borrower type who find refinancing more valuable than not refinancing. The remaining mass of that borrower type are non-refinancers $q_{\mathscr{N}}(j,\mathbb{K})$. Since the highest r' is r and $m' \geq m$, those with $\hat{\eta} = 0$ always find it optimal to refinance. Imposing that gives:

$$
q_{\mathscr{R}}(j,\mathbb{K}) = \begin{cases} \mu(j,m,r) & if \;\; E_{r'|\{\eta,j,\mathbb{K}\}} V_{\mathscr{R}}(r',\eta,j,\mathbb{K}) > V_{\mathscr{N}}(r,\eta,j,\mathbb{K}) \\ \lambda\mu(j,m,r) & otherwise \end{cases}
$$

$$
q_{\mathscr{N}}(j,\mathbb{K}) = \quad \mu(j,m,r) - q_{\mathscr{R}}(j,\mathbb{K})
$$

The bank contracts with the refinancing Type 1 borrower that meets this bank irrespective of the rate it offers but it contracts with the Type 2 borrower only if the rate this bank offers is lower of the two rates that the Type 2 borrower gets non-sequentially. Hence the expression in the maximization problem of the bank is similar to that in Burdett and Judd (1983). Hence, the distribution posted by a bank in equilibrium is also similar to that in that model. Note that the profit per borrower for the bank is the sum of the principal payment, interest payment, remaining mortgage balance payment less the gross interest payment on the savers' deposits that financed the mortgage, i.e.,

$$
m'(r'-i) = m'(\nu + r' + (1-\nu) - (1+i))
$$

3.2.3 Savers

Saver's problem is a standard problem of lifetime expected utility maximization where it earns bank profits, firm profits, risk-free return on the bonds and bank deposits and labor income and pays for the maintenance on the house, consumption, buys bonds and lends deposits to banks. Note that since savers do not have a mortgage, the cost of refinancing shock is irrelevant to them. Thus, the saver problem is:

$$
\max_{\{c_t,l_t,b_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta_s^{eff} u^s_{\mathscr{N},\hat{\eta}}(c_t,l_t)
$$

with the budget constraint

$$
c_t + d_t + b_t + \delta ph = \pi_t^{-1}((d_{t-1}+b_{t-1})(1+i_{t-1}) + \Pi^l_{t-1}) + w_t l_t + \chi_s^{-1}\Pi^f_t
$$

with initial conditions on the bonds and deposits:

$$b_{-1} = d_{-1} = 0$$

and the labor effort limit normalization:

$$l_t \leq 1$$

In the budget constraint, Π_t^f are the profits from intermediate goods producers in the economy, and bank profits $\Pi^l(\mu)$ are the profits earned by all banks:

$$\Pi^l(\mu) = \chi_s^{-1} B\mathscr{P}(\mu)$$

and deposits demanded $d(\mu)$ are the mortgage balances of refinancers and non-refinancers of both types of borrowers:

$$d(\mu) = \chi_s^{-1} \int\int \{\theta^{LTV} ph \sum_{j=1}^{2} q_{\mathscr{R}}(j,\mathbb{K}) + \pi(\mu)^{-1} m(1-\nu) \sum_{j=1}^{2} q_{\mathscr{N}}(j,\mathbb{K})\} dmdr$$

3.2.4 Firms

The final good producer solves a static problem of choosing each intermediate good input $y_t(k)$ to purchase at the price $P_t(k)$ and producing the final good sold at price P_t as below:

$$\max_{y_t(k)} \; P_t\left(\int_0^1 y_t(k)^{\frac{\varepsilon-1}{\varepsilon}} dk\right)^{\frac{\varepsilon}{\varepsilon-1}} - \int_0^1 P_t(k) y_t(k) dk$$

The intermediate good k producer chooses price $P_t(k)$ and produces the demanded $y_t(k)$ as below:

$$y_t(k) = a_t l_t(k)$$

where $l_t(k)$ is labor hours and a_t is the total factor productivity. In this model, I assume $a_t = a$, a constant. These intermediate good producers are subject to price-stickiness, in particular, a fraction Ψ of them are unable to update their price in any period.

3.2.5 Monetary Authority

The monetary authority sets the nominal interest rate which is also the cost of lending as below:

$$1 + i_t = (1 + i_{t-1})^{\rho_i} (\pi_{t-1}^{\rho_\pi} (\frac{y_{t-1}}{y_{ss}})^{\rho_y} rr_{ss})^{1-\rho_i} u_{i,t}$$

where i_t is the interest rate, π_{t-1} is the inflation, y_{t-1} is the output of the economy, rr_{ss} and y_{ss} are the steady-state real rate and output respectively. The white noise shock process $u_{i,t}$ has variance σ_u^2.

3.3 Equilibrium

A competitive equilibrium in the above model is defined as a sequence of prices $\{w, i, P, \{P(k)\}_k, \pi, r\}_t$, borrower decisions $\{c, l, a, m^{'}\}_{\hat{\eta},j,t}$, saver decisions $\{c_s, l_s, d, b\}_t$, bank decisions $\{F\}_t$, firms' demands $\{y(k)\}_{k,t}$, $\{l(k)\}_{k,t}$, distribution of borrowers $\{\mu\}_t$ and its law of motion H such that borrowers of both types, savers, banks and firms optimize their problems, interest rate rule holds, H is consistent with borrower and bank decisions and all the markets below clear:

- Labor market: $\int l_t(k)dk = \chi_s l_{s,t} + \sum_{j=1}^{2} \int \{\lambda l_{0,j,t}(\mu_t) + (1-\lambda) l_{\eta,j,t}(\mu_t)\} d\mu_t$
- Bond market: $b_t = 0$
- Goods market: $\sum_{j=1}^{2} \int \{\lambda c_{0,j,t}(\mu_t) + (1-\lambda) c_{\eta,j,t}(\mu_t)\} d\mu_t + \chi_s c_{s,t} + \delta ph = w_t \int l_t(k)dk + \Pi_t^f$

3.3.1 Optimal Decision of a Bank

The ability to observe the refinancer's (m,r), their optimal decisions and the distribution μ allows statistical discrimination by the bank. A bank posts a rate according to its market power in the market, which is higher if a greater fraction of refinancers meet only one bank. As mentioned earlier, bank plays a mixed strategy as in Burdett and Judd (1983). At a higher rate, the profit is higher if the refinancer contracts with the bank and a lower rate, the probability of the refinancer contracting with the bank is higher. The different r' posted form a connected set and the proportion of lenders that post at most r', $F(r',\mathbb{K})$, is continuous.

Equating the profit at any rate r' posted by a bank to the profit by posting $r'=r$ in Equation 1 gives the distribution of lenders $F(r',\mathbb{K})$ according to the rates r' they post once they observe $\mathbb{K} := \{m,r;\mu\}$:

$$F(r',\mathbb{K}) = 1 - \frac{q_{\mathscr{R}}(1,\mathbb{K})}{2q_{\mathscr{R}}(2,\mathbb{K})}\frac{r-r'}{r'-i}$$

Solving for r' by setting $F(r',\mathbb{K})=0$ above gives the lower bound of this distribution:

$$\underline{r}' = i + (r-i)\frac{q_{\mathscr{R}}(1,\mathbb{K})}{q_{\mathscr{R}}(1,\mathbb{K}) + 2q_{\mathscr{R}}(2,\mathbb{K})}$$

As a numerical example, we plot this distribution in two cases with the same mortgage balance m and current mortgage rate r with the risk-free rate i, but with different ratios of the two types of borrowers in the Figure 1. In either of these cases, Type 2 borrowers, who get quotes from two banks and choose the minimum, effectively get lower rates than Type 1 borrowers. In the market with a higher fraction of Type 1 borrowers, the offered rates by banks are higher for both types of borrowers and are closer to the monopoly rate r. Thus, if there are more borrowers who get a quote from only one bank, even the borrowers who get two quotes end up with higher rates. Thus, the composition of types of borrowers with the same (m,r) plays an important role in the optimal decision of a borrower to refinance her mortgage.

Also, for any ratio of the two types of borrowers, the distribution of lenders is Pareto. Thus, many lenders post low rates but few post high rates. Hence, Type 1 borrowers are likely to get low rates but Type 2 borrowers are very unlikely to draw two high rates. This leads to isolation of Type 1 borrowers at high rates but not of Type 2 borrowers at low rates. That is why, as we will see later, statistical discrimination costs Type 1 borrowers a lot but does not benefit Type 2 borrowers.

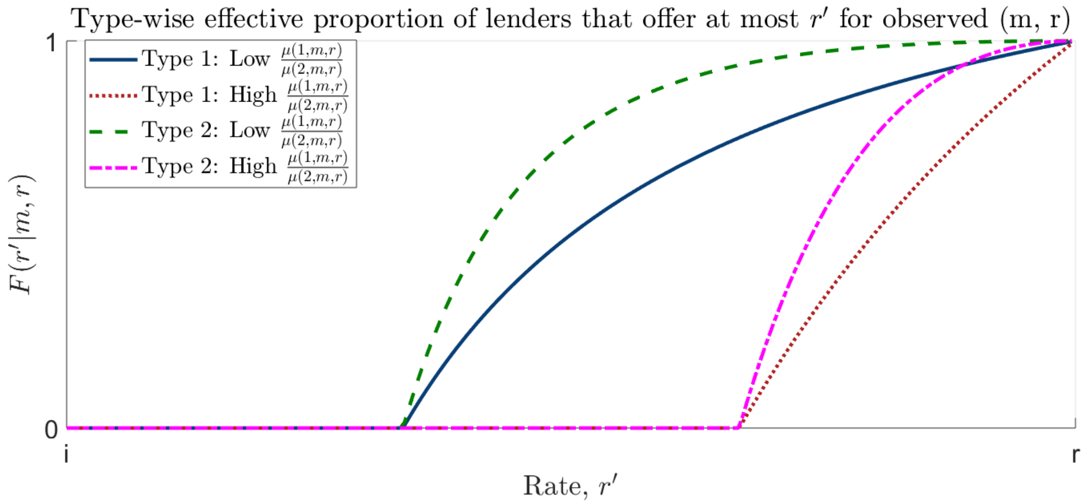

Figure 1: Effective distribution of lenders in benchmark economy (numerical example). Banks post lower rates on average when there are more Type 2 borrowers with the observed (m,r). Type 2 borrowers effectively get lower rates than Type 1 on average as they choose minimum of the two offers. Because of the Pareto distribution, Type 1 borrowers are likely to get low rates but Type 2 borrowers are unlikely to get high rates, leading to isolation of Type 1 borrowers at high rates.

3.4 Parameter Selection and Calibration

Most of the parameters are chosen from the literature. We calibrate four parameters of the model together to match four moments in the data by minimizing the maximum difference between the moments in the data and the corresponding moments generated by the model in its steady state. The results are summarized in Table 3.

In particular, the search cost parameter η, the fraction of Type 2 borrowers α, the borrower and saver labor disutility ψ_b and ψ_s respectively are calibrated together to match the average years after which a mortgage is refinanced in the Fannie Mae and Freddie Mac Loans data, the fraction of refinancers who consider more than one lender in the NSMO data, the aggregate labor supply of borrowers and the aggregate labor supply of savers. In addition to that, the refinancing cost shock is set equal to the fraction of homeowners who move per quarter in the US Census data.

I calibrate several of the standard parameters similar to the calibration in Greenwald (2018). The fraction of savers χ_s and the borrower discount factor β_b are matched using the Survey of Consumer Finances (SCF) 1998. The maximum LTV limit θ^{LTV} is set to 0.85 since there are a lot of mortgages with 80% LTV but also some with higher limits like 90% or 95%. The principal payment ratio ν is set to 0.435% as in Greenwald (2018). Saver discount factor β_s is set to match the 1993-1997 average 10-year rates (6.46%) and steady-state inflation π_{ss} matches the 10-year inflation expectations during the same period.

Parameter	Symbol	Value	Target/Source	Data	Model
Search Cost	η	1.116	Avg years to refinance (GSE)	3.58	3.57
Type 2 Borrowers	α	.54	Type 2/Refinancers (NSMO)	.478	.479
Refinance Cost Shock	λ	1.25%	Owners who move/Q (Census)	1.25	1.25
Borr. labor disutility	ψ_b	11.02	Total borrower labor supply	.33	.33
Saver labor disutility	ψ_s	7.02	Saver labor supply	.33	.33
Inv Frisch elasticity	ϕ	1	Standard		
Survival Probability	ζ	99.5%	50 yrs owner life (Census)		
Fraction of savers	χ_s	.681	SCF 1998		
Borrower discount factor	β_b	.965	SCF 1998		
Saver discount factor	β_s	.987	Avg. 10Y rate, 1993-1997		
Mortgage amortization	ν	.435%	Greenwald (2018)		
Max LTV ratio	θ^{LTV}	.85	Greenwald (2018)		
Housing preference	ξ	.25	Davis, Ortalo-Magne (2011)		
Housing stock	h	8.828	$p = 1$, SCF 1998		
Housing depreciation	δ	.5%	Standard		
Productivity	a	3.006	$y_{ss} = 1$		
Variety elasticity	ε	6	Standard		
Price stickiness	Ψ	.75	Standard		
Steady state inflation	π_{ss}	1.008	Greenwald (2018)		

Table 3: Benchmark calibration

Survival probability ζ matches the average life of a homeowner according to the US Census which is 50 years. Inverse Frisch elasticity ϕ, variety elasticity in the production function ε and price stickiness Ψ are as per the standard values in the literature. The productivity parameter a is chosen so that the steady state output is 1. Housing preference parameter ξ is chosen as in Greenwald (2018) to match housing expenditure estimated by Davis and Ortalo-Magne (2011). Housing stock h is chosen so that the ratio of saver house value to their income is the same as in SCF 1998 and the house price is 1 in the steady state. Housing depreciation δ value is standard in the literature.

4 Steady State Analysis

Now we describe the optimal refinancing decisions during the lifetime of the borrowers in the steady state of the model and then show how the invariant distribution in this steady state matches that in the data.

4.1 Refinancing Policy Functions

As seen in the model, borrowers have to pay a fixed cost of refinancing in order to reduce their mortgage payments and extract home equity. The potential reduction in mortgage payment is higher if the potential rate reduction is higher but lower if more home equity is extracted. The refinancing decision thus not

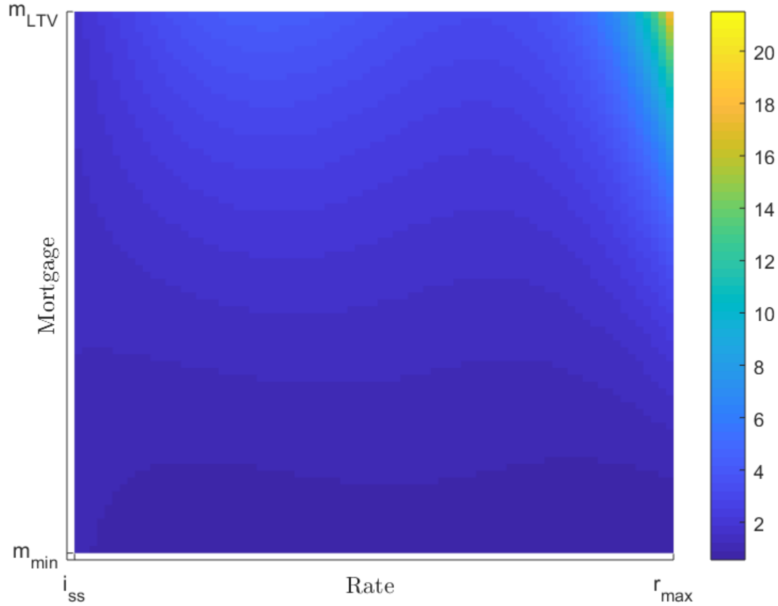

Figure 2: Ratio of mass of borrowers in steady state of benchmark model ($\frac{\mu(1,m,r)}{\mu(2,m,r)}$). Type 1 are isolated at high rate, high mortgage balance, thus easy to statistically discriminated.

only depends on the current mortgage balance and the current mortgage rate but also on the composition of the two types of borrowers in that state as it determines the potential rate reduction offered by banks who statistically discriminate between the two types.

Hence, to understand these decisions, it is crucial to understand the relative distribution of the two types of borrowers in steady state in the mortgage balance - mortgage rate space. This is shown in Figure 2. There are more Type 1 borrowers for each Type 2 borrowers at a higher mortgage rate and at a higher mortgage balance. The LTV limit mortgage balance (m_{LTV}) and the highest mortgage rate (r_{max}) is the state in which each borrower is born. Close to this state, there are much more Type 1 borrowers relative to Type 2 borrowers compared to that in the rest of the space. This is because at birth, Type 1 refinancers get higher rate than Type 2 because of their own search behavior. Once they get a higher rate, on their next attempt to refinance, banks can infer that any refinancer with such high rate is more likely to be Type 1 refinancer and thus offer them a high rate again, whereas the opposite happens to Type 2 refinancers at lower rates. This increases the isolation of Type 1 borrowers at high rates. Type 2 borrowers do not get as much isolated at lower rates because of the Pareto distribution of lenders implies that Type 1 refinancers are also likely to end up with low rates. Thus, the relative distribution of borrowers affects the distribution of banks based on their offer rates for each (m,r) state and thus affects the optimal decision of the borrowers in that state.

The refinance policy of each type of borrower in each state is shown in Figure 3. Note that in each state that Type 1 refinances, Type 2 also refinances; but not vice-versa as the fixed cost of refinancing is the same for both types whereas the benefit of meeting two banks always exceeds the benefit of meeting one bank. The three regions where borrowers do not refinance are explained in the figure. Firstly, the relatively high concentration of Type 1 borrowers close to m_{LTV} and r_{max} leads to greater market power for the banks, easier inference of type leads to stronger statistical discrimination and thus the offered rate reduction is low; hence the borrowers do not refinance in these states. Secondly, once the current rate becomes low enough, borrowers do not find it optimal to spend the fixed cost of refinancing in order to reduce their mortgage payment further. Thirdly, even at higher mortgage rates, once the mortgage balance becomes low enough, the mortgage payment is thus low enough that refinancing to get a lower rate is not worth the fixed cost.

The different arrows in Figure 3 describe the refinancing policy during the life of a typical borrower. First, at birth (at m_{LTV} and r_{max}), both types refinance and get lower rates and stay at the same mortgage balance level m_{LTV}. Second, if the new mortgage rate is low enough, the borrower does not find it optimal to spend the refinancing cost to get a lower rate or to extract the home equity; thus she only repays her mortgage for the rest of her life. Third, if the new mortgage rate is not that low, the borrower refinances her mortgage after some periods. The number of periods for which she waits before refinancing depends on the potential rate improvement and the extractable home equity post refinancing. It should be noted that the borrower waits longer to refinance even though she has a higher current mortgage rate. This is because the relative mass of Type 1 borrowers to Type 2 borrowers is much higher at these high mortgage rates as seen in Figure 2 which makes it very easy for the banks to statistically discriminate in these states, thus reducing the potential rate improvement for borrowers. Eventually, when the benefit of extracting the accumulated home equity becomes high enough, the borrowers refinance at these high rates, get lower rates and cash out the home equity. Whether the borrowers refinance again in their lifetime depends on the new rate they end up with. Thus, the distribution of the two types of borrowers in the mortgage balance - mortgage rate space is crucial to determine the optimal refinance policy of the borrowers. As described in Section 2.1.2, this optimal refinance policy is also observed in the data and thus the above novel mechanism is validated.

The relevance and importance of heterogeneity in mortgage search can be seen by removing the mortgage search heterogeneity and have only Type 1 borrowers or only Type 2 borrowers in the economy with all the other parameters kept the same. In the economy with only Type 1 borrowers who meet one lender at refinancing, any lender offers only the monopoly price (current mortgage rate) to each borrower in each

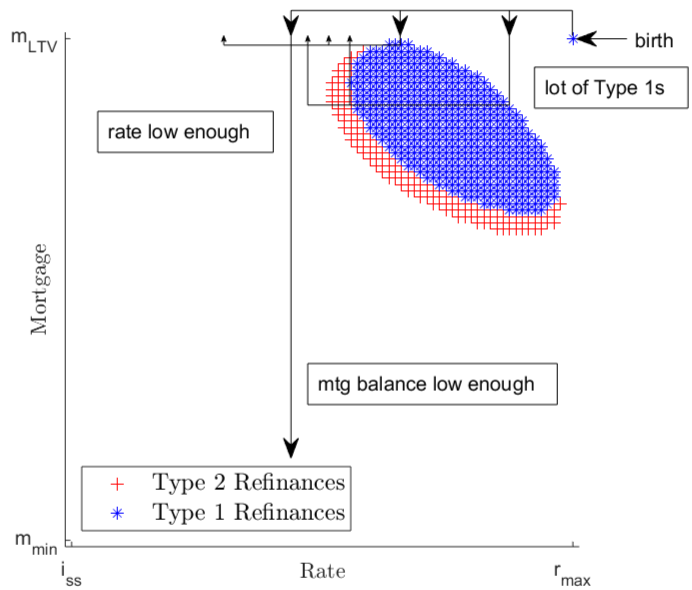

Figure 3: Lifetime refinance policy in steady state of benchmark model. Borrowers isolated at high rate and mortgage balance do not refinance.

state if they try to refinance and hence, since there is no rate improvement, the Type 1 borrower does not find it optimal to spend the refinancing cost and so does not refinance in any state. Her mortgage rate remains at the highest level with which she was born. On the other hand, in the economy with only Type 2 borrowers who meet two lenders at refinancing, any lender offers only the competitive price (cost of lending rate) to any borrower trying to refinance. Hence, given the calibrated cost of refinancing, the Type 2 borrower finds it optimal to refinance in each state where the rate is above the competitive rate. Her mortgage rate becomes the lowest level available as soon she refinances immediately after birth. Contrasting these vanilla optimal refinance policies with that observed in Figure 3, the optimal refinance policy of the borrowers in their lifetime crucially depends on the mortgage search heterogeneity studied in this paper. Similarly, heterogeneity in mortgage search also generates the heterogeneity in mortgage rates observed in the data.

4.2 Matching the Data

In Figure 16 below, we find that the model is a good representative of the data by comparing the steady state distribution of the two types of borrowers with respect to their mortgage balance and mortgage rate to that seen in the data. For this comparison, we choose data from the month of November 2015 as the current coupon rate of a 30 year fixed rate agency mortgage-backed securities (secondary market rate), which is the cost of financing for mortgage lenders, was relatively steady for more than 2 years before this month (See Figure 14) . We also consider other months for this comparison and find similar results. To have enough data to build a distribution, we choose to work with the HMDA data. We divide the MSAs into above-median and below-median search activity as in Section 2.3.1. First, we look at the distribution of the fraction of the initial mortgage amount that is unpaid in this month (top-left panel of Figure 16). We find that entities that search less tend to have a higher mortgage balance. That matches closely with the unpaid mortgage balance distribution in the steady state of the model (top-right panel of Figure 16). Second, we look at the distribution of the difference between the mortgage rate and the secondary market rate at the time of origination of the unpaid mortgages in this month. We find that the entities that search less tend to pay a higher mortgage rate premium. This property matches that in the model. The distribution of rates in the model is Pareto whereas the distribution in the data is highly left-skewed. One of the main results because of the Pareto distribution is that Type 1 borrowers are isolated and thus much worse off but Type 2 borrowers are not isolated and thus not much better off due to statistical discrimination. This result is valid in the data since the distribution is left-skewed. The relative difference in the rate secured by the two types of borrowers in the model matches closely with that in the data. This is shown in Table 7 which states that the difference between those who search less and those who search more in their mean of the distribution of rate or mortgage balance relative to the overall mean is comparable in the data and the model. Thus, the model is a good representative of the data and thus the steady state results and the results from the counterfactual experiments are reliable.

5 Effects of Statistical Discrimination in Steady State

Now we will describe the effects of statistical discrimination in the steady state of the model on borrowers at different stages of their life, on the steady state distribution of borrowers, on their absolute and relative welfare. For this, we compare them in the benchmark economy which has observable mortgage to a counterfactual economy in which the current rate and balance is unobservable to the lender, they offer rates based on the aggregate ratio of the two types of borrowers and thus there is no statistical discrimination.

5.1 Evolution of State with Borrower's Age

In the Figure 4 below, we show the evolution of the distribution of mortgage rate and mortgage balance of the two types of borrowers in the steady state of the model. Each borrower is born with a high rate and mortgage balance equal to the LTV limit. All of them refinance in the first period. The initial separation in the rate distribution between them thus created is because of their own search and the market power of the lender based on the aggregate ratio of the two types. Hence, it is the same in the benchmark and the counterfactual economy. But with this increased separation in types, the lenders have more information about the borrowers based on their current rate. Type 1 borrowers are likely to be at higher rates and Type 2 at lower rates. In the benchmark economy, thus, higher the rate of a refinancer, more likely she is to be of Type 1, less likely she is to meet another lender, more the market power of the lender, thus higher the offer rate. This results in increase in the separation in mean rates between the two types once they start refinancing again. After about five years of age, only those of Type 2 borrowers whose cost of refinancing becomes zero enter the market whereas a few more Type 1 borrowers enter the market to get lower rates. Hence, note that I plot values for first ten years when most of the refinancing action takes place and also that I have dropped the first period percentage refinancers in the plot since it is 100. In contrast to this, in the counterfactual economy without statistical discrimination, the initial separation decreases as the lenders are no longer able to condition their offer rates based on the current rate and balance of the refinancer. So, many more Type 1 borrowers who got higher rates at the start find it optimal to refinance again and reach lower rates whereas Type 2 borrowers, who no longer gain by being at lower rates, wait longer to collect more home equity and then refinance. Thus, the difference in rates reduces sharply as they refinance again. After about five years of age, both types refinance only if their cost of refinancing becomes zero. Thus, much of the difference in rates in the benchmark economy is explained by statistical discrimination. The initial variation in rates for Type 1 borrowers is higher as Type 2 borrowers draw twice from the same distribution and thus get a tighter distribution of rates. This variation increases as they refinance more since those at high rates get less reduction and those at low rates get more reduction because of statistical discrimination. This effect goes away when the mortgage becomes unobservable. In terms of mortgage balance, in the benchmark economy, Type 1 borrowers keep on refinancing at later ages also and hence stay at a higher mortgage balance than Type 2 borrowers. This also goes away if there is no statistical discrimination. Hence, statistical discrimination has a big impact on lender's offer rates and thus on refinancing decisions and the resulting distribution of rates and home equity.

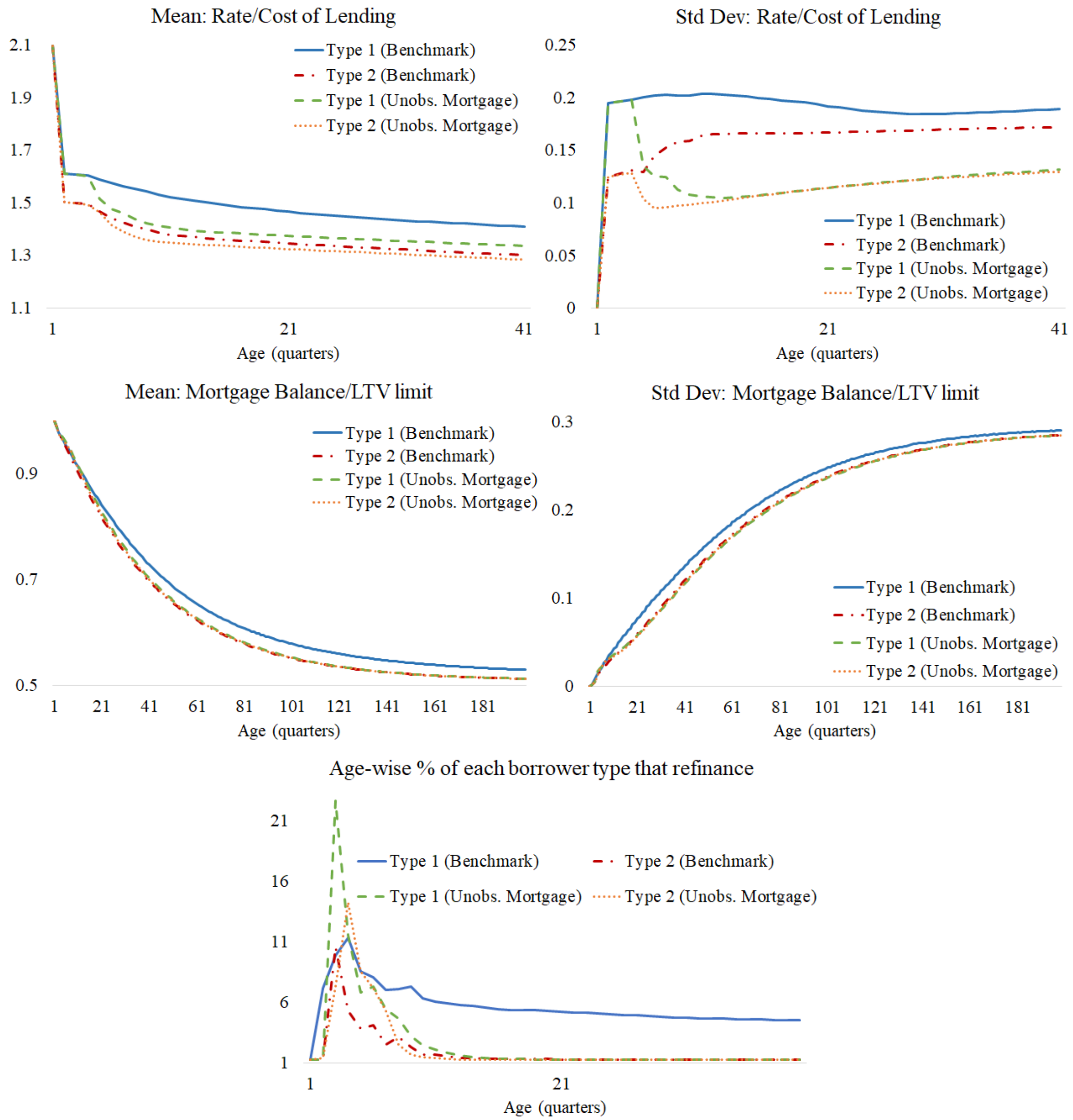

Figure 4: Borrower's age-wise state & refinancing in steady state, with & without statistical discrimination. Due to statistical discrimination, difference in rates between two types amplifies with age (top left); those who get a high (low) rate keep getting high (low) rate, hence higher variation (top right); Type 1 refinance more frequently, thus collect less home equity (mid left); few Type 1's get low rates soon, others keep refinancing to get low rates, thus higher variation (mid right); Type 1 keep refinancing to reach low rate (bottom).

5.2 Isolation of Type 1 borrowers

We have shown in Section 4.1 how Type 1 borrowers become isolated at higher mortgage rate and balance in steady state. Now let us see how much of this isolation depends on statistical discrimination. The plots on the left-hand side of Figure 5 are of the relative distribution of the two types in the steady state of the benchmark economy. It can be seen how because of this relative distribution, at high mortgage rate and balance, it is much easier to statistically discriminate and infer the type of the borrower. At the same time, at low rates, there is not much isolation of Type 2 borrowers because of the Pareto distribution of lenders mentioned earlier and also because of the presence of old Type 1 borrowers who are present at these lower rates. On the other hand, on the right-hand side are the same plots for the economy without statistical discrimination. Due to repeated refinancing, the two types collect very similar home equity and they end up at higher rates mainly because of their own lack of search. There is hardly any isolation of Type 1 borrowers in any region of the state space. Thus, the isolation of Type 1 borrowers is mainly due to statistical discrimination.

5.3 Welfare Costs

Statistical discrimination has big welfare costs. Borrowers are willing to pay 30% of their quarterly income (about $3,300) to make mortgage unobservable and thus remove statistical discrimination. Out of this, Type 1 are willing to pay 52% and Type 2 are willing to pay 8% of their quarterly income. Left panel of Figure 6 shows the welfare cost of statistical discrimination to borrowers at each age. Its right panel shows the average welfare cost of statistical discrimination for a borrower in economies with different fraction of Type 2 borrowers (α^* is the calibrated value), keeping all other parameters same. The cost is defined as the difference in values for a borrower in the economies with and without statistical discrimination expressed in consumption good equivalents. At birth, statistical discrimination costs little but as soon as they start refinancing, it costs much more to Type 1 borrowers than Type 2. Once they stop refinancing, they make smaller mortgage payments over time and so the cost of statistical discrimination diminishes. For Type 2 borrower, the cost is positive because they do not gain much out of statistical discrimination due to the Pareto distribution and the existence of old Type 1 borrowers at low rates in steady state, as mentioned before. Even after several rounds of refinancing, about half of Type 2 borrowers have a positive cost and the other half have a smaller negative cost. Those Type 2 borrowers with low rates who decide to refinance, extract home equity, make larger mortgage payments and are worse off due to statistical discrimination (positive welfare cost) whereas those Type 2 borrowers

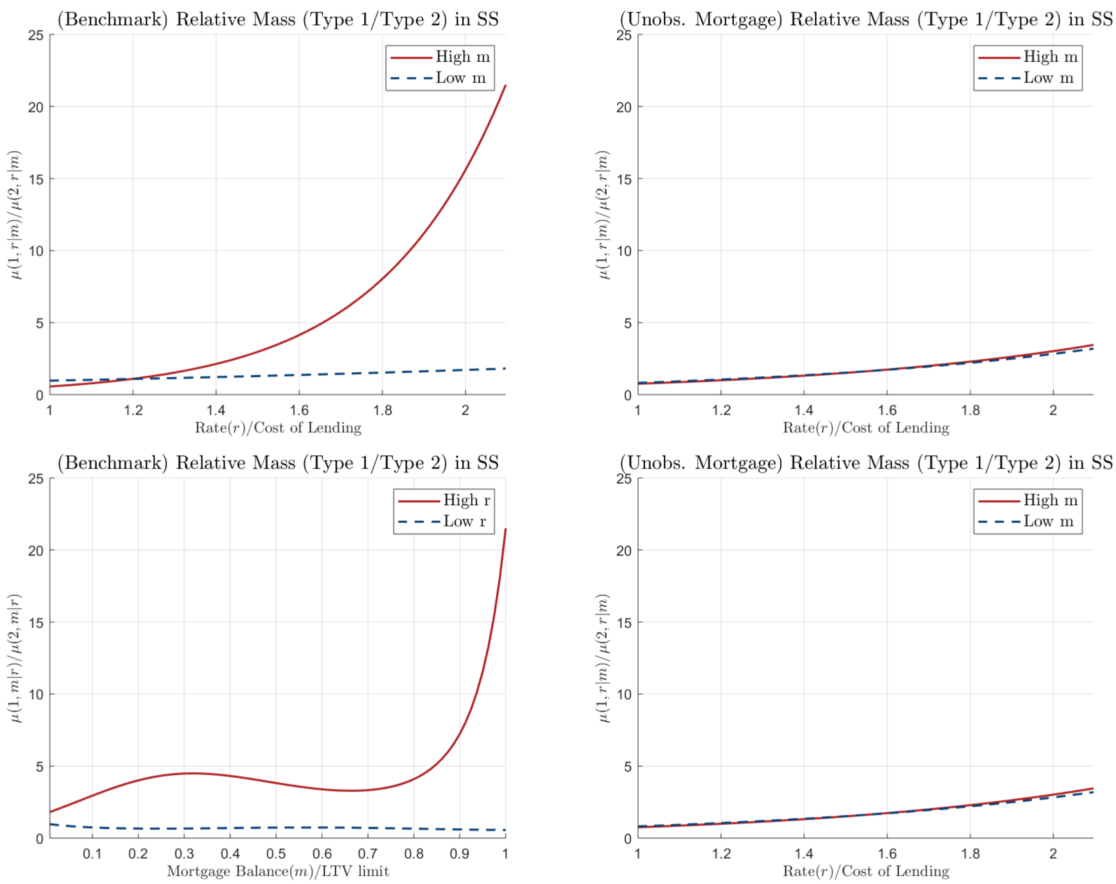

Figure 5: Relative mass of borrowers (Type 1/Type 2) in steady state with and without statistical discrimination. Shows isolation of Type 1 borrowers at high mortgage rates and balances in benchmark model is due to statistical discrimination.

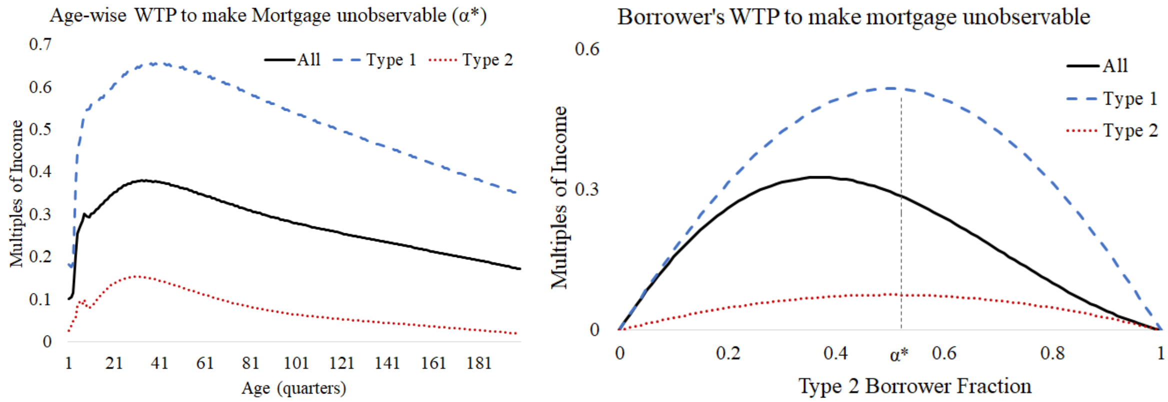

Figure 6: Welfare cost of statistical discrimination: Small at birth, increases with each round of refinancing, quadruples in eight years. Type 2's do not benefit out of it since they are not isolated at low rates due to the Pareto distribution of lenders seen earlier in Figure 1. It is the lenders who benefit by statistical discrimination. (left). It is much higher for the isolated Type 1 borrowers in the calibrated model, reduces if there are more Type 2 borrowers in economy (right).

with high rates who decide not to refinance as they will be perceived as being Type 1, collect home equity, make smaller mortgage payments over the rest of their life and thus benefit out of statistical discrimination (negative welfare cost). If there are more Type 2 borrowers in the economy, i.e., move to the right of α^* in the right panel of Figure 6, lender loses their average market power, fewer Type 1 are isolated at high rate and balance and thus the welfare cost of statistical discrimination decreases. Thus, this way of increasing mortgage search in the economy leads to significant reduction in welfare cost of statistical discrimination.

Statistical discrimination explains more than two-thirds of the difference in welfare between the two types. Type 1 borrowers are willing to pay 70% of their quarterly income (about $7,700) to switch to Type 2 in the benchmark economy which reduces to 21% in the counterfactual economy with unobservable mortgage. Left panel of Figure 7 shows the age-wise difference in welfare between the two types with and without statistical discrimination and the right panel shows the difference in welfare between the two types with and without statistical discrimination in economies with different fraction of Type 2 borrowers (α^* is the calibrated value), keeping all other parameters same. The difference in value is expressed in consumption good equivalents. Similar to earlier, the difference in welfare between types is small at birth but as they start refinancing and thus getting separated, this difference increases and once they are done with refinancing, the difference in welfare diminishes as they make smaller mortgage payments. Without statistical discrimination, instead of the difference increasing, Type 1 borrowers at higher rates refinance sooner than Type 2 and close the gap in welfare and this gap keeps reducing with time. As earlier, if there are more Type 2 borrowers in the economy, i.e., move to the right of α^* in the right panel of Figure 7, the

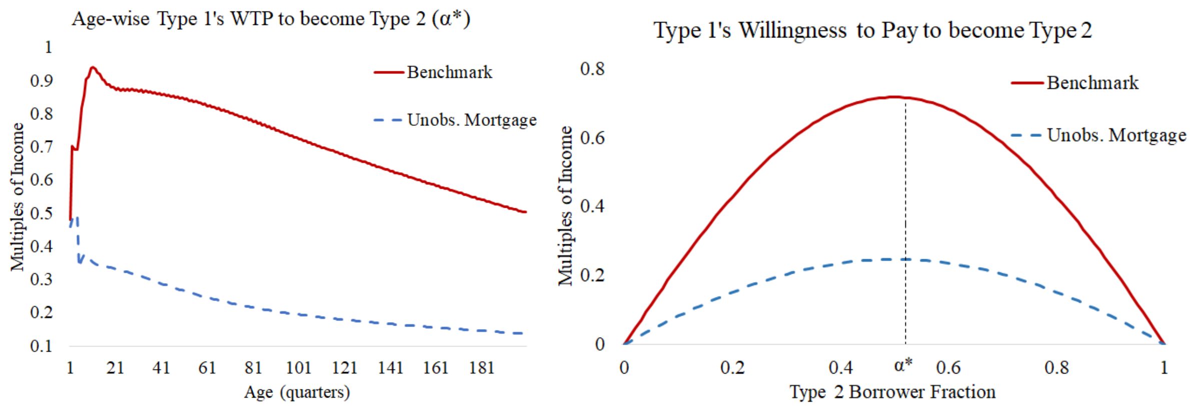

Figure 7: Welfare difference between the two types: At birth, it is small and not driven by statistical discrimination, but increases sharply with each round of refinancing due to increasing isolation of Type 1's (left). Two-thirds of the welfare difference is due to statistical discrimination in the calibrated model, it would decrease if there are more Type 2's in economy (right).

difference in welfare between the two types decreases and statistical discrimination accounts for less of it. Thus, this way of increasing mortgage search also reduces the difference in welfare between the two types.

6 Effect of increasing mortgage search

An explicit aim of the Consumer Financial Protection Bureau (CFPB) is to increase the mortgage search in the economy. But how this mortgage search increases can be important for welfare consequences for the borrower, especially in the presence of statistical discrimination. We will consider two ways of increasing mortgage search: first in which one-third of Type 1 borrowers now become Type 2 and second in which Type 2 borrowers meet 3 lenders instead of two. We find that welfare cost becomes two-third of the benchmark level in the first case whereas it becomes four times the benchmark level in the second case. Thus, while implementing policies related to increasing mortgage search, it is important to evaluate whether non-shoppers search more or shoppers search more.

6.1 Non-shopper searches more

In this economy, we increase the fraction of Type 2 borrowers α from 0.54 to 0.68 based on our findings about search intensity in the HMDA data[2]. As seen in Section 5.3, this results in welfare gains for both

[2] The measure of search intensity in a MSA-year, applications withdrawn/applications accepted has mean 0.24 and standard deviation 0.07. Assuming that each borrower withdraws their application only once, about one-third (0.24/0.76) of borrowers

types of borrowers and the difference in welfare between the two types also decreases. Welfare cost becomes two-third of the benchmark level and difference in welfare falls by 15%. Below we compare the steady state refinancing decisions and distribution in this economy with that in the benchmark.

6.1.1 Steady States Comparison

In this alternate economy with more borrowers who meet two banks, banks offer lower rates for both types of borrowers as there are fewer borrowers who meet one lender relative to those who meet two lenders. Fewer Type 1 borrowers are isolated in the high rate and mortgage balance region. Hence, refinancing is now optimal not only in each state in which refinancing is optimal in the baseline model but also in even more states for both types of borrowers. This is shown in Figure 17. Hence in the steady state distribution of this alternate economy, for both types of borrowers, the mean rate is lower; since the offered rate is lower on refinancing, the frequency of refinancing over the life of a borrower is lower; since refinancing frequency is lower, the average home equity is also larger than in the baseline model. This is shown in Table 8.

6.2 Shopper searches more

Another way of increasing mortgage search is to make Type 2 borrowers meet three lenders instead of two when they refinance. This changes the distribution of lenders based on their offer rates as Type 2 borrowers now choose minimum of three rates. Like earlier, many lenders post low rates but now many also post high rates. This increases the isolation of Type 1 borrowers as Type 2 borrowers are still unlikely to end up with those high rates. Due to the increased isolation, Type 1 borrowers get higher rates, refinance more frequently in the hope of getting a low rate, collect less home equity, keep making higher mortgage payments and thus have welfare cost of statistical discrimination five times as much as in the benchmark economy. Type 2 borrowers now benefit out of the increased statistical discrimination and thus have a slightly negative welfare cost of statistical discrimination. The average borrower's welfare cost becomes four times that in benchmark case and the difference in welfare between types becomes three times that in benchmark case. Thus, the two ways of increasing mortgage search have opposite welfare effects.

are shoppers in an MSA-year with average search intensity. In an MSA-year with one standard deviation higher search intensity, this number increases to about half (0.32/0.68). Hence, the increase in α by about .14 represents a one-standard deviation increase in the fraction of Type 2 borrowers in the economy.

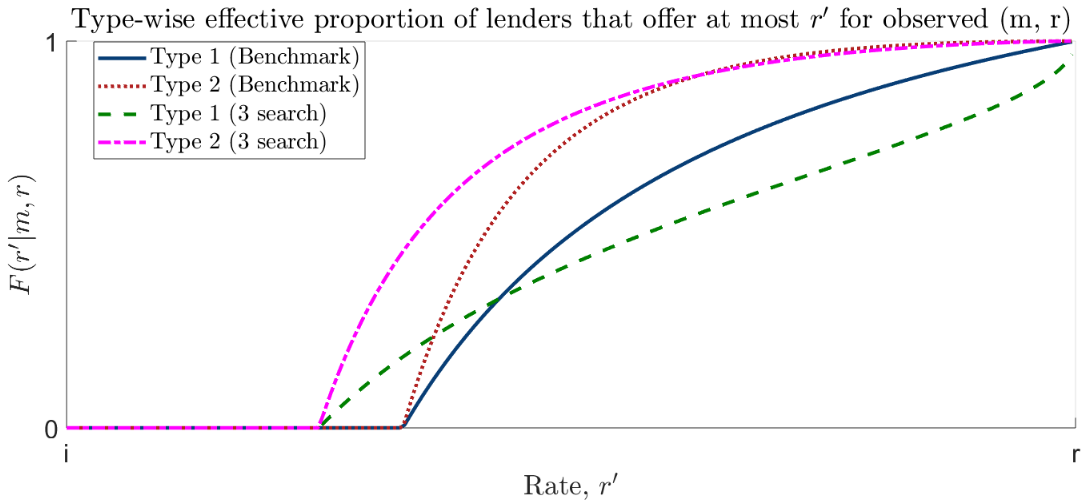

Figure 8: Effective distribution of lenders in benchmark vs. economy where Type 2 meet 3 lenders (numerical example). If Type 2 meet 3 lenders, Type 1 borrowers are much more likely to be isolated at high rates.

6.2.1 Increased isolation of Type 1 borrower

Now, with the same mass of the two types of refinancers, the mass that a lender contracts with as shown in Equation 1 becomes

$$(q_{\mathscr{R}}(1,\mathbb{K})+3(1-F(r',\mathbb{K}))^2 q_{\mathscr{R}}(2,\mathbb{K}))$$

Thus, now proportion of lenders who post no greater than r' is:

$$F(r',\mathbb{K}) = 1-\sqrt{\frac{q_{\mathscr{R}}(1,\mathbb{K})}{3q_{\mathscr{R}}(2,\mathbb{K})}\frac{r-r'}{r'-i}}$$

with lower bound:

$$\underline{r}' = i+(r-i)\frac{q_{\mathscr{R}}(1,\mathbb{K})}{q_{\mathscr{R}}(1,\mathbb{K})+3q_{\mathscr{R}}(2,\mathbb{K})}$$

Figure 8 shows the effective distributions of lenders that the two types of borrowers meet in the benchmark economy and that where Type 2 meet 3 lenders. Now, Type 1 borrowers are much more likely to end up at higher rates and with repeated refinancing in presence of statistical discrimination, this leads to their increased isolation. They are also likely to end up at low rates and hence Type 2 borrowers are not isolated at low rates.

Figure 9 (similar description to Figure 4) shows how Type 1 borrowers are now stuck at much higher rates. The variance of rates they get is also higher than benchmark as more lenders post extreme rates. Hence, Type 1 borrowers at high rates keep refinancing hoping to get a low rate and thus collect less home

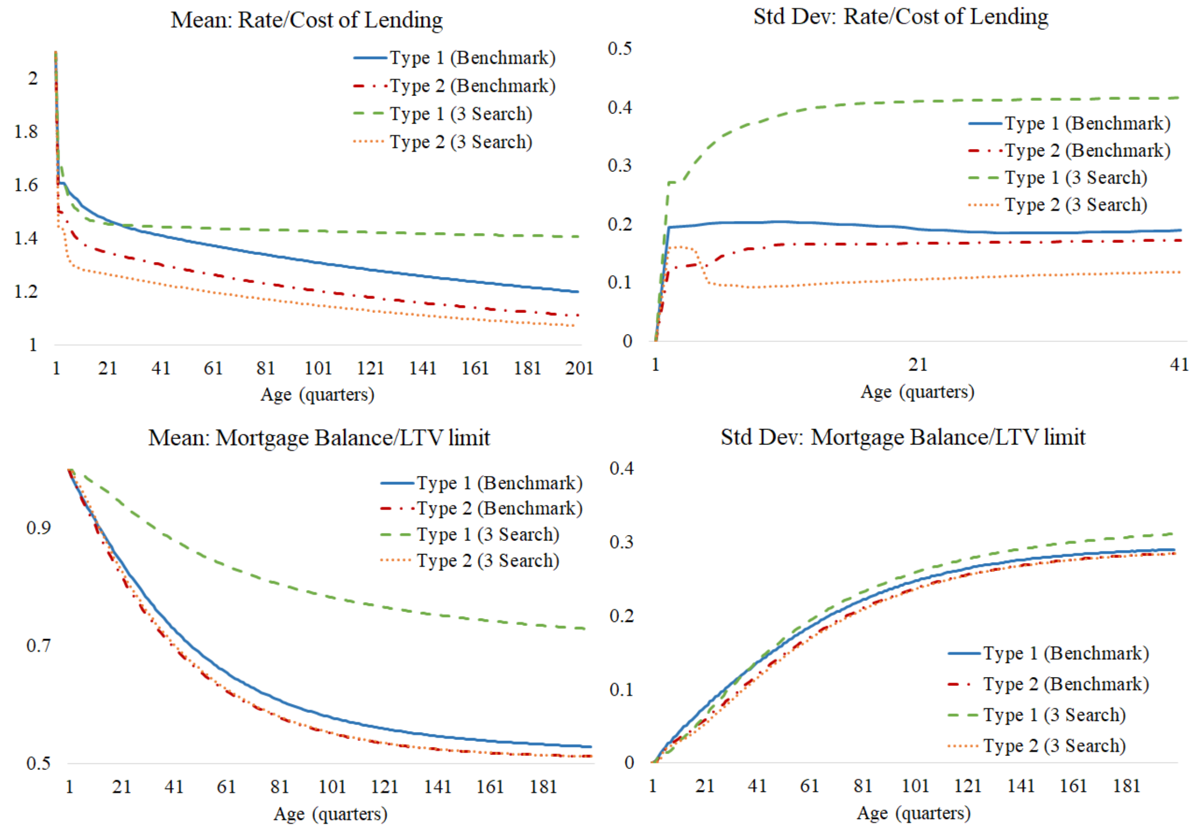

Figure 9: Borrower's age-wise state in steady state of benchmark model and when Type 2 meet 3 lenders (thus more search). Due to increased ability to statistically discriminate in the counterfactual economy, isolation of Type 1 borrowers increases, they get much higher rates, Type 2 get lower rates than benchmark (top left); As more extreme rates are posted, variation in rates that Type 1 get increases, while Type 2 search and get low rates more often than benchmark (top right); As Type 1 are likely to get low rates, they keep on refinancing, thus their home equity stays low (bottom left); As few Type 1 get low rate soon while others keep refinancing to get low rates, the spread in mortgage balance increases (bottom right).

equity and make higher mortgage payments. Type 2 borrowers get much lower rates on average with a much tighter spread. This increased isolation of Type 1 borrowers increases the ability to statistically discriminate and drastically increases the welfare cost of Type 1 borrower.

6.2.2 Increase in welfare costs

As shown in the left panel of Figure 10 (similar description to right-panel of Figure 6), welfare cost of statistical discrimination for Type 1 borrowers becomes five times (265% of quarterly income) that in benchmark economy whereas it becomes slightly negative (-2%) for Type 2 borrowers as they now benefit by statistical discrimination. For an average borrower, the welfare cost thus becomes four times (125% of quarterly income) that in benchmark. In the right panel of Figure 10 (similar description to right-panel of

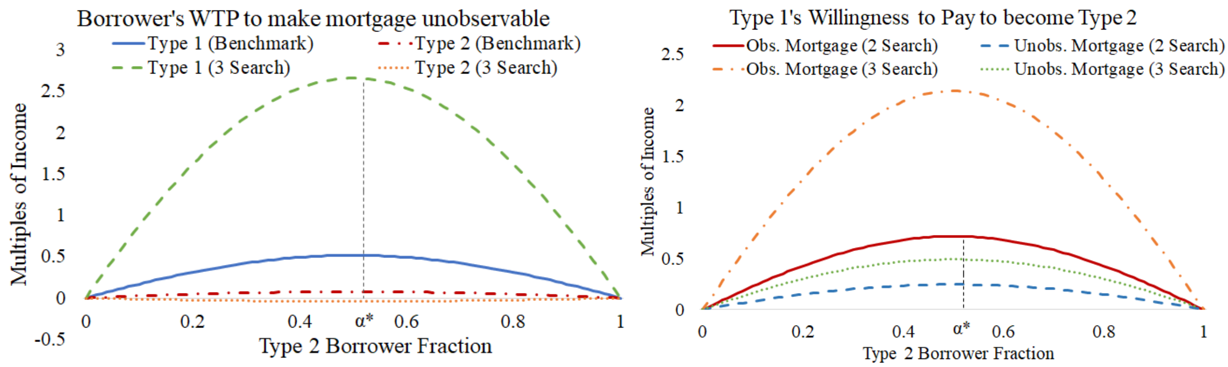

Figure 10: Welfare cost of statistical discrimination - Benchmark vs. Type 2 meet 3 lenders (thus more search): Increased isolation of Type 1 borrowers cost them a lot in the counterfactual economy, Type 2 now benefit by statistical discrimination. Thus, lenders benefit much more (left). Now, statistical discrimination accounts for three-fourths of the difference in welfare between the two types, compared to two-thirds in benchmark (right).

Figure 7), the difference in welfare between the two types now becomes three times (213% of quarterly income) that in benchmark and three-fourths of it is explained by statistical discrimination. Thus, this method of increasing search has reduced the welfare of a borrower significantly and also increased the difference in welfare between the two types.

7 Monetary Policy Transmission to Consumption

Mortgage refinancing is an important channel of monetary policy transmission to consumption in the US. An interest rate cut influenced by Federal Reserve's open market operations leads to a reduction in the cost of lending which leads to a reduction in mortgage rates. This encourages households to refinance their mortgages to a lower rate and also extract their home equity at the same time, thus increasing their current consumption. Statistical discrimination described so far in the paper can have a significant impact on this transmission mechanism since the reduction in rates offered to refinancers depends on the composition of shoppers and non-shoppers at any current mortgage. As seen in the steady state results, statistical discrimination hurts Type 1 borrowers much more than it benefits Type 2 borrowers. Similarly, we find in our experiments below that as statistical discrimination becomes stronger, Type 1 borrower's consumption response becomes smaller but that of Type 2 remains almost the same. Below, we look at the response to a one-period unexpected 25 basis points expansionary monetary policy shock in four different economies with differing ability to statistically discriminate: benchmark, unobservable mortgage, one-third of Type 1 meet 2 lenders, Type 2 meet 3 lenders.

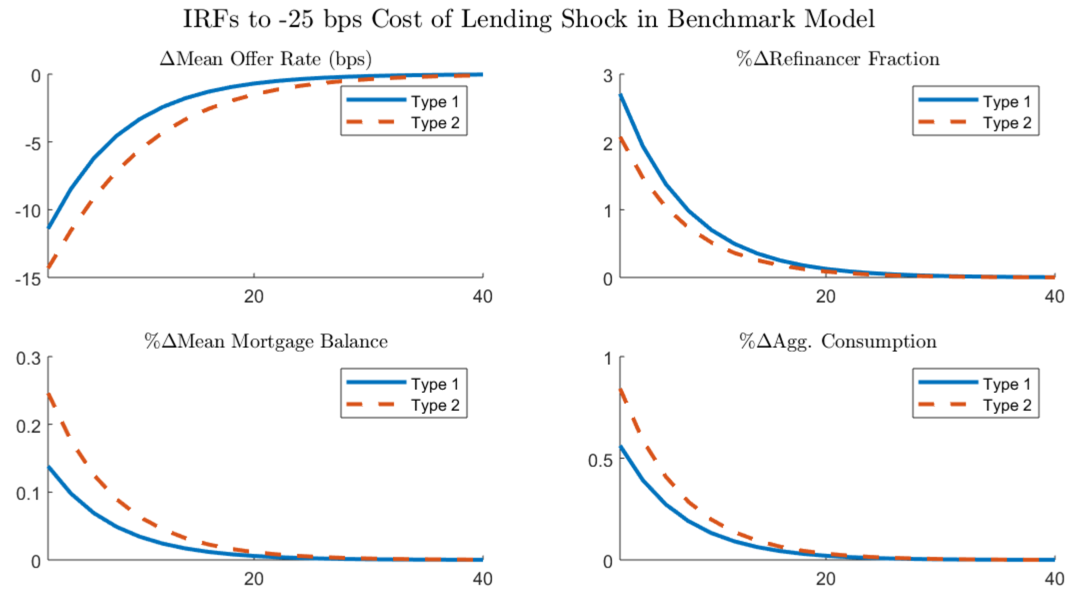

Figure 11: Those who meet more lenders have a bigger consumption response to an expansionary monetary shock as in steady state, they get lower rates sooner, thus refinance less often, thus collect more home equity. Due to lower rates in steady state, fewer of them refinance to the shock (top right).

7.1 Benchmark Economy

Type 1 borrowers, isolated at higher rates and thus easier to statistically discriminate, respond much less to the expansionary monetary shock than Type 2 borrowers. We calculate the impulse response functions to a 25 basis points reduction in the risk-free rate in the steady state of the baseline model. As Figure 11 shows, the rate offered to Type 2 borrowers reduces more than that to Type 1 borrowers because of the isolation of Type 1 borrowers in steady state and that Type 2's are more likely to be in states with more Type 2 borrowers. But since they already have a lower mortgage rate in steady state, the increase in the percentage of refinancers among Type 2's is smaller. At the same time, Type 2's have a smaller mortgage balance in steady state and thus a bigger home equity. Thus, the fewer additional Type 2 refinancers extract greater home equity than Type 1's and thus their mortgage balance increases more. This results in Type 2 borrowers (about 0.84%) having a bigger consumption response to the monetary shock than Type 1 borrowers (about 0.57%). At the aggregate, the consumption of borrowers increases by about 0.71% in response to this monetary policy shock which is line with the consumption response found in the literature.

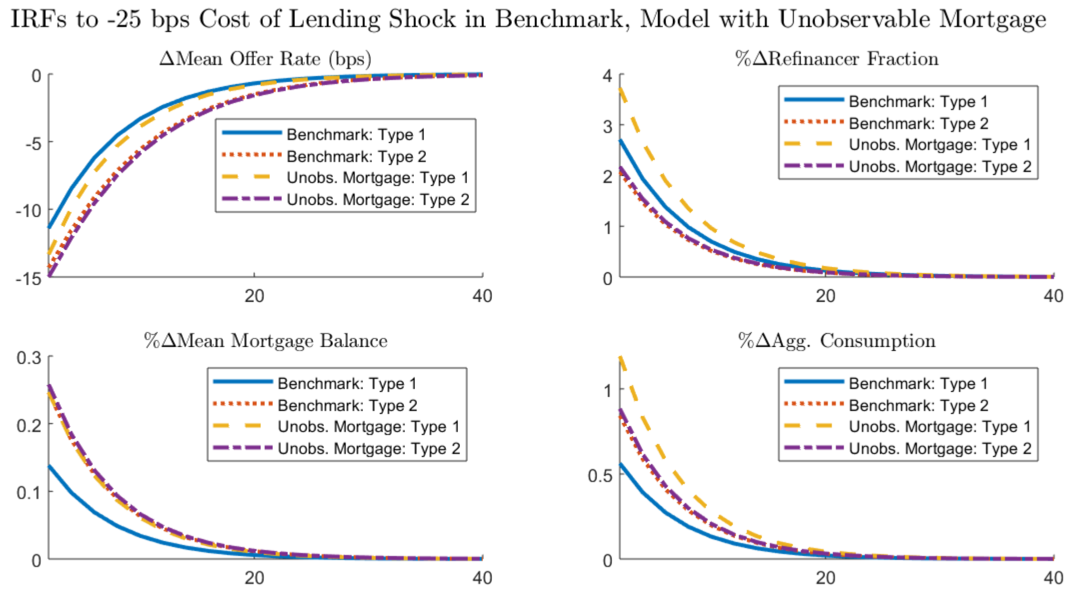

Figure 12: Without statistical discrimination, Type 1 are no longer isolated, have lower rates, more home equity, bigger consumption response; Type 2 who did not benefit much by statistical discrimination have similar response to benchmark

7.2 Economy with unobservable mortgage

This economy with no statistical discrimination results in much bigger consumption response of Type 1 borrowers than benchmark as they are no longer isolated at high rates and almost same response of Type 2 borrowers as they are not affected much by statistical discrimination. We shock the steady state of this economy with the same 25 basis points reduction in the risk-free rate. As seen in Figure 12, Type 2 get a similar rate reduction whereas Type 1 get much lower offer rates as they are not isolated at high rates. The increase in refinancers among Type 2's is small compared to benchmark. Type 1 refinancers increase compared to benchmark because of the lower offer rates. They have bigger home equity in steady state compared to benchmark, thus their increase in mortgage balance is bigger. Home equity of Type 2 borrower is almost the same as in benchmark, hence the increase is also similar. Thus, the consumption response of Type 2 borrower (0.88%) is similar to that in benchmark but that of Type 1 (1.21%) is much bigger. Thus, without statistical discrimination, the consumption response of shoppers remains almost similar but that of non-shoppers increases a lot as they are no longer isolated at high rates.

7.3 Economies with more mortgage search

Now we look at two economies described earlier with different ways of increasing mortgage search, an explicit aim of the CFPB. We find that consumption response of Type 1 borrowers moves in opposite directions compared to the benchmark whereas that of Type 2 remains almost same.

7.3.1 One-third of Type 1 meet 2 lenders

This economy with more search and weaker ability to statistically discriminate results in bigger consumption response than benchmark for both types of borrowers. We shock the steady state of this economy with the same 25 basis points reduction in the risk-free rate. As seen in Figure 18, the average offer rate reduces more as both types of borrowers get lower rates since there are fewer Type 1 borrowers isolated at high rates and the reduced market power due to the presence of more Type 2 borrowers. But since both types of borrowers are at lower rates in steady state, the percentage increase in the refinancers of both types is smaller compared to that in the baseline economy. At the same time, both types of borrowers have more home equity in steady state and thus the fewer additional refinancers extract a greater amount of home equity compared to the baseline. The higher home equity extraction results in a bigger borrower consumption response in the alternate economy (1.08%, Type 1: 0.93%, Type 2: 1.15%) compared to that in the baseline economy (0.71%). Thus, having fewer borrowers who do not search for a mortgage results in a bigger borrower consumption response in the economy.

7.3.2 Type 2 meet 3 lenders

This economy with more search and stronger ability to statistically discriminate results in much smaller consumption response of Type 1 borrowers than benchmark due to their increased isolation and almost same response of Type 2 borrowers. We shock the steady state of this economy with the same 25 basis points reduction in the risk-free rate. As seen in Figure 19, the difference in offer rates for the two types increases compared to benchmark. The increased isolation of Type 1 borrower results in much higher offer rate. The increase in refinancers among Type 2's is small as they are already at lower rate compared to benchmark. Type 1 refinancers decrease compared to benchmark because of the higher offer rates. They also have smaller home equity in steady state compared to benchmark, thus their increase in mortgage balance is lower. Home equity of Type 2 borrower is almost the same as in benchmark, hence the increase is also similar. Thus, the consumption response of Type 2 borrower (0.92%) is similar to that in benchmark but that of Type 1 (0.31%) is much smaller. Thus, if shoppers search more, the consumption response of shoppers remains almost similar but that of non-shoppers decreases a lot due to the stronger ability to statistically discriminate.

8 Conclusions

In this paper, we develop a model with heterogeneity in mortgage search of borrowers who refinance leading to difference in mortgage rates not only due to their own search but also crucially because of the lender's ability to statistically discriminate based on their current mortgage. This ability becomes more potent with each round of refinancing as it isolates those who meet only one lender at high rates.

When calibrated to the US mortgage data, we find that this statistical discrimination has big welfare costs for borrowers, especially for those who meet only one lender to refinance their mortgage; and conversely, big welfare gains for lenders. It accounts for most of the welfare difference between those who meet one lender and others who meet multiple lenders. Increasing mortgage search is an explicit aim of CFPB. We find that the welfare consequences for borrowers of increasing mortgage search depend critically on how the mortgage search increases. In particular, if non-shoppers search more, welfare increases significantly as statistical discrimination becomes less potent. But instead, if shoppers search more, then welfare decreases a lot as non-shoppers are increasingly isolated at high rates making it easier for lenders to statistically discriminate.

Statistical discrimination also reduces monetary policy transmission to consumption significantly, especially that of borrowers who meet one lender to refinance and are isolated at high rates. Note that our benchmark results are conservative since we restrict those who meet multiple lenders to meet exactly two lenders which is not true for one third of them. Thus, while designing any policy that affects the mortgage market, it is important to assess its impact on this less-intuitive ability to statistically discriminate in this market.

Our analysis and findings are grounded in data as we find a wide dispersion in the rates offered to observably similar refinancers, a lack of search for their mortgage among half the refinancers who thus end up with higher rates and smaller mortgages, U-shaped time-to-refinance in current mortgage rate and balance, and a larger home equity extraction rate in areas with more mortgage search activity.

Looking ahead, it would be important to understand the source of the lack of search in this market. For example, if low-income households are more likely to live in financial deserts and thus have a low likelihood of meeting multiple lenders to get a mortgage, their resulting higher rates and lower home equity can amplify the consumption inequality borne purely out of income inequality. Incorporating other dimensions of a refinancer like her age, income, house size and price that can be used by a lender for statistical discrimination would also be important to capture this mechanism more accurately. Endogenizing search behavior with heterogeneous search costs will allow a refinancer to search differently based on her income, house size and house price; and thus allow the aggregate search and statistical discrimination to vary according to business cycles.

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A Appendix

Supplementary Figures and Tables

See main text for more figures and tables.

A.1 Data Analysis

A.1.1 Refinance behavior

	Loan Age
State	-3.772***
$State^2$	0.076***
FICO	0.008***
LTV	0.012***
CLTV	0.055***
DTI	0.015***
Number of Borrowers	1.446***
First Home Flag=Y	0.685***
Adjusted R^2	0.251
Observations	6867645
***: p-value < 0.01	

Table 4: Loan Age at which it is refinanced is concave in the State (rate*balance/100,000). This is consistent with the refinance policy of borrowers in the model. (Data: GSE mortgages originated before 2011)

A.1.2 Search behavior (NSMO)

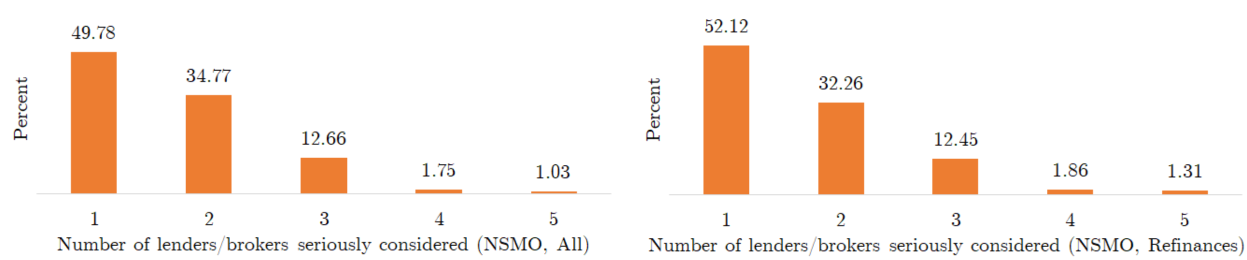

Figure 13: Search Behavior according to NSMO. Half of all borrowers consider only one lender. (Left: All, Right: Refinancers only)

A.1.3 Cost of Lending and Federal Funds Rate

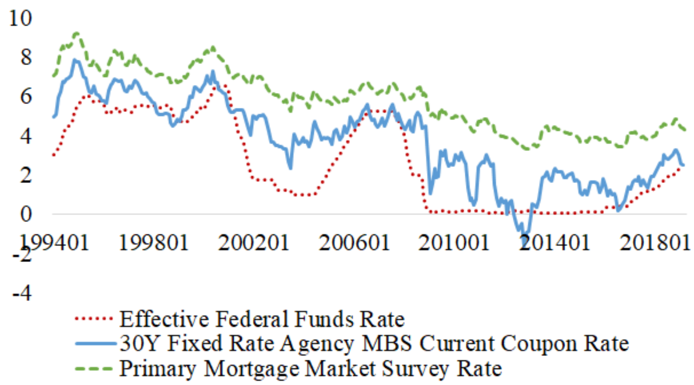

Figure 14: Cost of Mortgage Lending (MBS Rate) & Average mortgage rate (PMMS) moves with Federal Funds Rate

	Federal Funds Rate	Constant	Adjusted R^2	Observations
MBS Rate	0.81***	1.69***	0.764	302
PMMS	0.59***	4.30***	0.75	302

***: p-value < 0.01

Table 5: Cost of Mortgage Lending (MBS Rate) moves much more tightly with Federal Funds Rate than the Average mortgage rate (PMMS)

A.1.4 Search, Rates and Home Equity Extraction (HMDA, GSE)

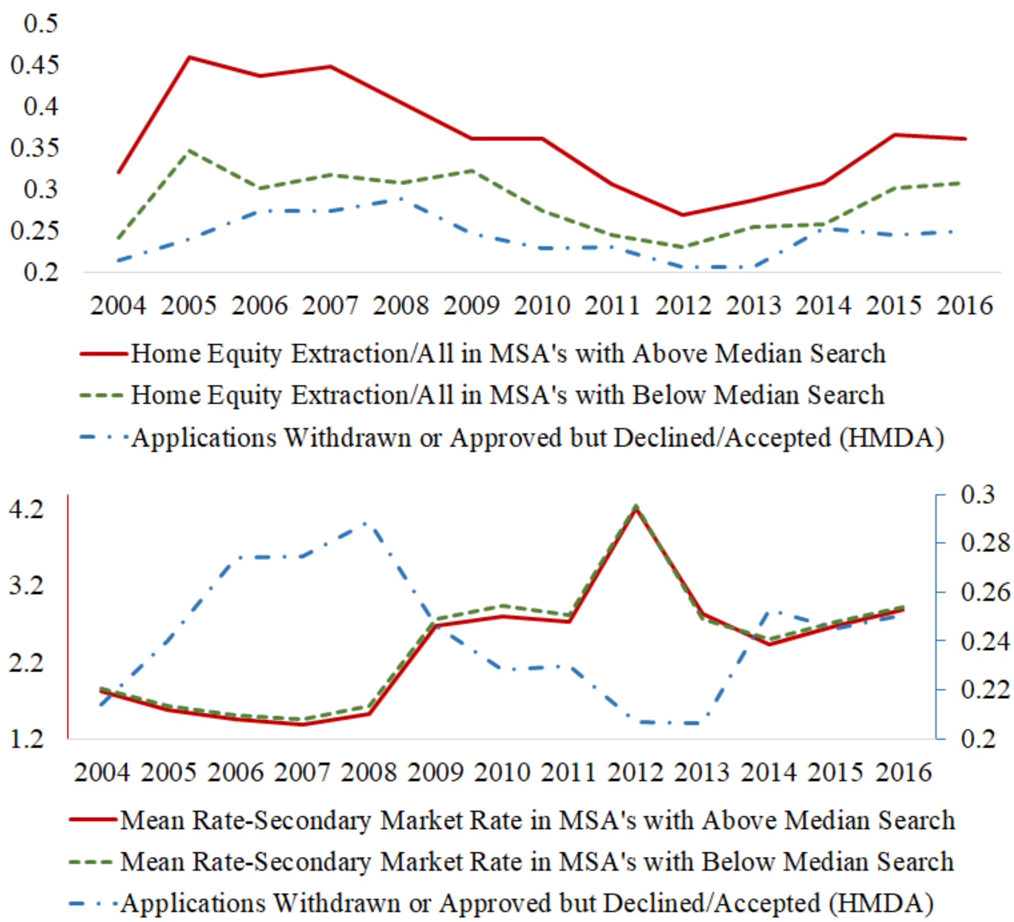

Figure 15: Mortgage Search (HMDA), Home Equity Extraction (GSE) and Rate Spread (GSE) across MSA-years. Top: Home equity extraction moves in the same direction as mortgage search, across years and MSAs. Bottom: Average rate spread moves in opposite direction as mortgage search, across years and MSAs.

	PMMS	Search Fraction	PMMS*Search Fraction	Adjusted R^2	Observations
Home Equity Fraction	-.002396***	-.01904***	.005953***	0.546	1624795
mean	4.973723	0.2312726			
std. dev.	1.032283	0.0889403			

Table 6: MSAs with more mortgage search extract more home equity in response to reduction in mortgage rates. When rates fall by 1 sd, 37% more home equity is extracted in an MSA with 1 sd more search

A.2 Model Results

A.2.1 Steady state match with Data

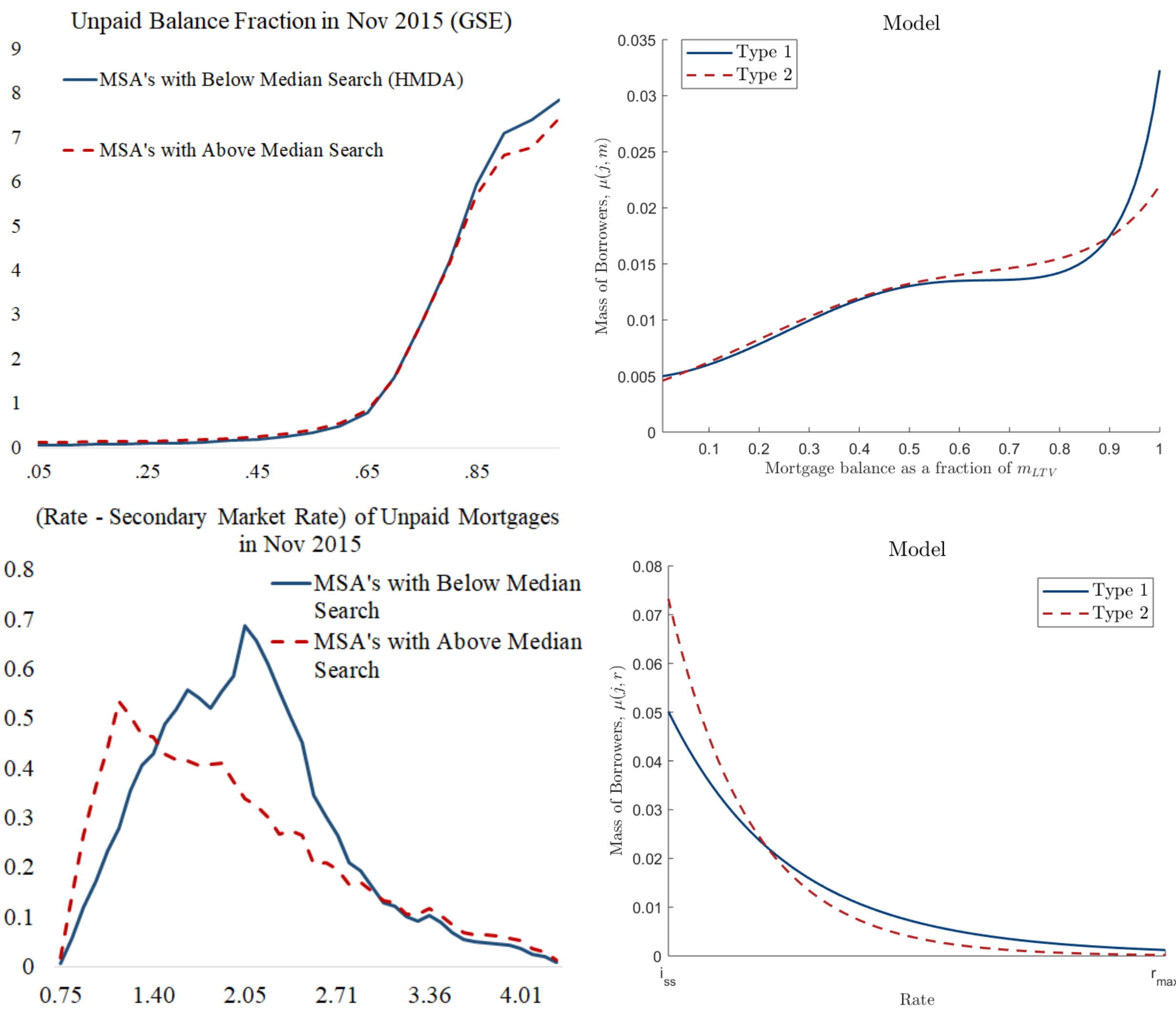

Figure 16: Borrower distribution in steady state of benchmark model vs. Data (HMDA, GSE) (Untargeted). Rate spread in data is significantly left-skewed, similar to the Pareto distribution in model, validating the results.

	Data	Benchmark Model
Mean Mortgage Balance Difference/Overall Mean (%)	1.12	1.27
Mean Rate Difference/Overall Mean (%)	2.86	3.13

Table 7: Relative (Type 1 - Type 2) Borrower Distribution Means in steady state of Benchmark Model vs. Data (HMDA, GSE) (Untargeted)

A.2.2 Benchmark vs. More Type 2's: Steady state comparison

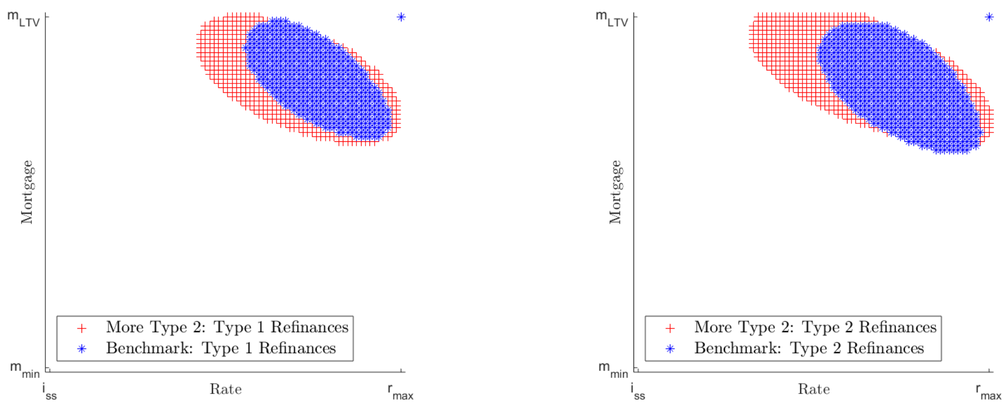

Figure 17: Refinancing policy in steady states of Benchmark vs. Economy with more Type 2 borrowers. With more Type 2's around, offer rates reduce, refinancing optimal in more states for both types.

Weighted Means	$\frac{Type\ 2}{Borrowers}$=0.54		$\frac{Type\ 2}{Borrowers}$=0.68	
$\frac{q_1}{q_2}$	2.817		2.154	
	Type 1	Type 2	Type 1	Type 2
$\frac{r}{i_{ss}}$	1.26	1.18	1.22	1.09
% who refinance	3.93	2.71	3.18	2.23
$1-\frac{m}{m_{LTV}}$	.383	.405	.394	.417

Table 8: Mean borrower type ratio, rate, refinance frequency and home equity in steady states of benchmark (Column 2) versus economy with more Type 2 (Column 3). Due to more Type 2 borrowers on average in each state, both types get lower rates, thus they refinance less often, thus collect more home equity in steady state.

A.2.3 Monetary Policy with More Search

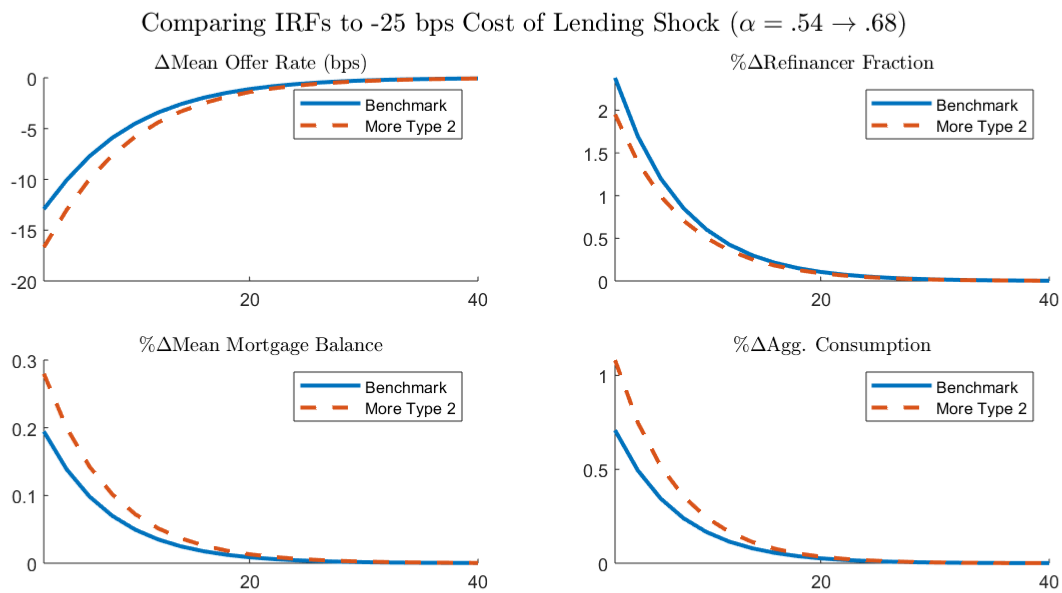

Figure 18: With fewer Type 1 borrowers in economy, fewer are isolated; that and the reduced market power leads to lower rates, more home equity, bigger consumption response for both types (hence, showing only the aggregate values).

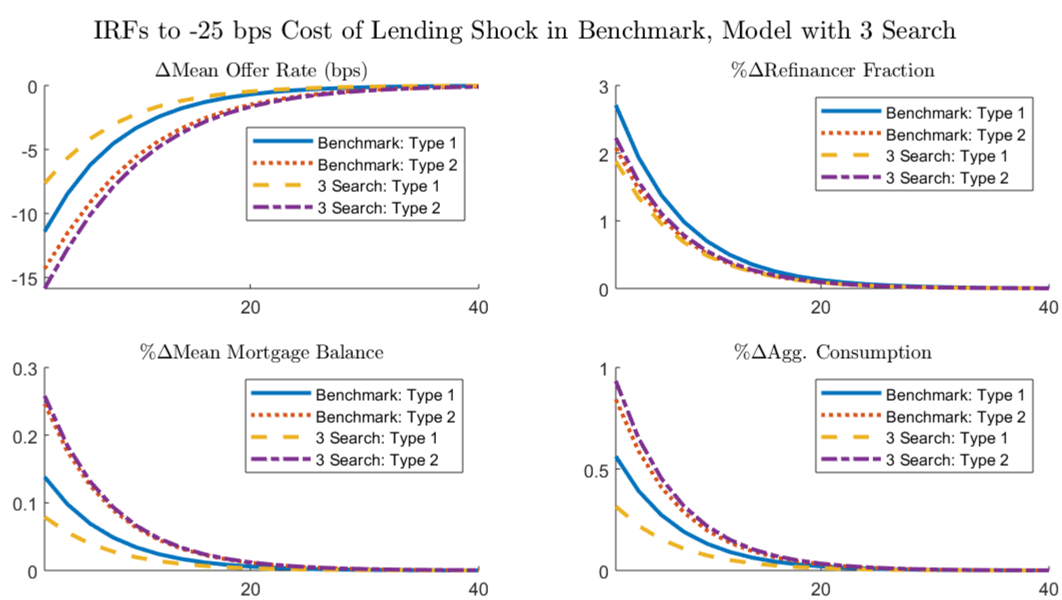

Figure 19: When Type 2 meet 3 lenders, isolation of Type 1 increases, ability to statistically discriminate becomes stronger, thus consumption response of Type 1 becomes much smaller; that of Type 2 remains almost same