Lenders' competition and macro-prudential regulation: A model of the UK mortgage supermarket

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Abstract

This paper develops and estimates an empirical model of the UK mortgage market and studies the effect of macro-prudential regulation on lending activity. We estimate a discrete-continuous choice demand model of mortgages with a new administrative dataset of the universe of residential mortgage originations. Borrowers decide jointly the lender, the rate type and the leverage, facing a non-linear price schedule and affordability constraints on their choice sets. We find: 1) 10 basis points increase in the interest rate decreases the market share of a product by 6% on average; 2) a 1% increase in the interest rate decreases loan demand by about 4%; 3) both elasticities are heterogeneous across leverage levels, borrower types and lenders. We derive a pricing equation that takes into account default and refinancing risk and we characterize the Nash-Bertrand equilibrium, subject to risk-adjusted capital constraints. We use the estimated parameters to study the pass-through of capital requirements in two different counterfactual regimes.

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1 Introduction

The mortgage market plays a central role in the recent academic and policy debate about the cause, consequences and remedies of the financial crisis (Mian and Sufi, 2015). On the demand side, mortgages represents the most important financial liabilities for households' in developed countries and their choices have important implications for household consumption and business cycle fluctuations (Campbell et al., 2003; Jordà et al., 2016). On the supply side, the increase in competition in the lending market may have led to greater risk-taking by firms, threatening financial stability. Following the 2008 crisis, competition in the mortgage market has declined as a result of failures and consolidations (Vives, 2010; Andrés and Arce, 2012; Jiang et al., 2016). On the policy side, capital requirements and macro-prudential regulation have been at the center of the debate since 2008 and reforms to the regulatory system have been substantial, with more under discussion (Admati and Hellwig, 2014; Acharya et al., 2014; Behn et al., 2016).

In this paper we develop an equilibrium model to study borrowers' choice, lenders' competition and capital regulation in the mortgage market. First, we develop a discrete choice model for mortgages and estimate it with loan-level data on the universe of mortgage originations in the UK in 2015-16 and a new identification strategy that exploits supply side shifters coming from capital regulation. Second, we use the demand parameters to characterize the equilibrium, accounting for default and refinancing risks; calibrate the supply side and evaluate the impact of risk-adjusted capital requirements and loan-to-income limits on lenders' marginal costs. Finally, we study two counterfactual macro-prudential policies, that affect the capital-requirements for different lenders and mortgage products.

We find that an increase in 10 basis points in the interest rate leads to an average decrease in the share of a mortgage product of about 6%, with significant heterogeneity across lenders and leverage levels. We find that risk-weighted capital requirements have a significant impact on lenders' cost: a 1% higher capital requirement increases the cost of issuing a mortgage by about 1%. With the estimated model, we study the effect of changing capital requirements on interest rates and market shares. First, we simulate a scenario in which we ban internal rating based models for the calculation of risk-weights and eliminate the risk-weight gap between lenders with internal model and lenders with a standardized approach. The higher capital requirements will increase costs and be passed on to interest rates. The elimination of the risk-weight gap will favour challenger lenders and tilt incentives to originate high leverage products, possibly increasing financial instability. Second, we simulate an alternative policy, which gives to lenders on a standardized approach a "representative" internal model. This will decrease overall interest rates and allow challenger lenders to increase their shares; higher leverage products will be penalized by the more risk-sensitive approach, which now affects all lenders.

We provide new reduce form evidence on the impact of macro-prudential regulation on lending activities by looking at mortgage pricing and originations. We use a new dataset with the loan-level capital requirements, matched to mortgage originations, to show the impact of larger capital requirements on loan-level interest rates. We exploit the joint variation across lenders and leverage levels and find that in 2015-16 a 1% higher capital requirement leads to a 0.7 basis point higher interest rate. These effects are statistically significant and have a larger magnitude in the markets for first-time-buyers and home-movers, while they are not significant for remortgagers.

We develop a second reduce-form identification strategy that exploits an exogenous variation in the incentives to originate high loan-to-income (LTI) mortgages following a recommendation of the Financial Policy Committee (FPC) in June 2014. We create a measure of exposure to the policy by looking at the pre-existing share of high LTI mortgages and divide the sample between lenders with high and low exposure. Our difference in difference model reveals that "treated" lenders decrease their share of mortgage with an LTI above 4.5 by almost 4% relative to the "control" lenders. The results are not affected when we add a full set of time and lenders' fixed effects. As expected, the impact of the FPC recommendation on LTI limits is strongest for first-time-buyers, lower for home-movers and not significant for remortgagers.

To study these and alternative macro-prudential policy, we develop a structural model of mortgage demand and pricing. On the demand side, we model borrowers' mortgage choice as a logit function of prices, characteristics (e.g. rate type, lender, loan-to-value) and latent demand. We construct borrowers' unobservable choice sets from the equilibrium choices of similar borrowers and restrict it according to affordability rules in the market for mortgage approvals. We then estimate demand using microdata on the universe of mortgage originations in the UK in 2015-16 and product level supply-side shifters. We match the loan-level data on borrowers' choice with information on lenders' funding costs and regulatory capital and we use them as instruments to identify demand. We study the elasticity of borrowers' demand to interest rates and fees, and their valuation for different brands and product attributes, allowing for preference heterogeneity across borrowers. We decompose the elasticity of mortgage demand into a leverage choice, captured by the maximum loan-to-value limit, and type-lender choice.

We find that a 10 basis points increase in the interest rate decreases the market share of a product by about 6% and the share of the other mortgage products increase by about 0.10%. We decompose the elasticity of mortgage demand into a leverage choice, captured by the maximum loan-to-value limit, and lender choice. First, we find that an increase in the interest rate by 10 basis points for all products in a loan-to-value band decreases the share of that loan-to-value band by about 5%. Second, an increase in the price by 10 basis points of all products of the big six lenders decreases their market share by approximately 0.60%, while with the same price increase challenger banks and building societies will lose 6% of their market share.

On the supply side, we develop an empirical mortgage pricing equation that accounts for both refinancing and default risk. We model lenders as heterogeneous multi-product firms offering differentiated mortgages and competing on prices, subject to regulatory constraints. In the UK mortgage market, lenders offer a menu of products with advertised interest rates and borrowers purchase them at the given price through branches, intermediaries and online comparison websites, resembling the situation faced in an actual or online supermarket. We use the elasticity parameters from the demand estimation together with lenders' first order conditions and additional loan-level information on arrears and refinancing to calibrate the supply side and compute equilibrium prices. We study the shadow value of macro-prudential regulation, exploiting heterogeneity in the risk weighted capital requirement across lenders and leverage levels.

We find an average mark-up of about 15%, with significant heterogeneity across loan-to-value bands and lenders. First, mark-ups decrease monotonically with the loan-to-value. Second, the average mark-up for the largest six lenders (the "big six") is about 16%, while building societies and challenger banks have an average mark-up of 14% and 11%. We estimate the impact of risk-weights on lenders' cost. We find an elasticity of marginal cost to risk weight of about 1.

The estimated demand and supply model allow us to investigate the effect of macro-prudential regulation in the mortgage market. We perform two counterfactual simulations to study the implication of differences in model-based capital regulation for mortgage pricing and risk-taking, accounting for lenders' best response to the new regime and to competitors' behaviour. Figure 1 shows the heterogeneity in risk weights across two relevant dimensions: lenders and loan-to-values. First, the calculation of risk weights depends on the model lenders adopt. For lenders adopting a standardized approach (SA) risk weights are fixed at 35% for loan-to-value ratios up to 80%, and are then increased to 75% on incremental balances above the 80%. In contrast, lenders adopting an internal rating based model (IRB) have risk weights that increase with the loan-to-value ratio along the whole distribution. The gap between the average IRB risk weight and the SA risk weight was about 30% points for loan-to-value mortgages below 50%, compared to less than 15% for loan-to-value mortgages above 80%. We use the structural model to study the consequences in terms of products offered, prices and market shares, as a result of closing this gap.

First, we simulate an equilibrium without internal models for calculating capital requirements. We find that eliminating internal models increase the cost for banks adopting them, which are then passed on to borrowers with higher initial rates. However, challenger lenders and building societies, which are mostly on SA, have more competitive prices and therefore gain market shares. Moreover, the less risk-sensitive standardized approach leads to an increase in the share of high loan-to-value mortgages.

Second, we allow lenders adopting a standardized approach to develop an internal model, with the capital requirements of the average IRB lender. In this case costs are lower and prices go down. The effect is stronger on the challenger lenders and even more on building societies, which do not suffer from the larger cost of higher capital requirements. However, the more risk-sensitive approach which is now affecting all lenders leads to a decrease in the share of high loan-to-value mortgages, which limit the welfare gain from lower prices, especially for first-time-buyers.

Related literature. This paper contributes to several strands of literature. First, we provide a framework to study households' demand of their mortgage and optimal leverage, which complements existing approaches in household finance (Campbell et al., 2003; Campbell, 2013). We differ from previous models in the household finance literature and take an approach inspired by the industrial organization literature on differentiated product demand (Lancaster, 1979). We assume that each mortgage can be represented as a bundle of attributes and that borrowers have preferences for these attributes. In this way we can capture heterogeneity in household preference along several dimension, that are otherwise hard to model together (e.g. fixed vs variable, lender, leverage). Moreover, we improve on the existing household finance literature by accounting for the supply side response to demand preferences.

Second, we provide new estimates of how households respond to changes in interest rates, complementing previous studies that employed bunching techniques and surveys (Best et al., 2015; Fuster and Zafar, 2015; DeFusco and Paciorek, 2016). We apply techniques from industrial organization and marketing to deal explicitly with households' heterogeneity in preferences, non-convexities in the budget constraint and omitted variable problems (Hendel, 1999; Allenby et al., 2004; Dubé, 2004; Thomassen et al., 2015). We study the impact of interest rates on household leverage choice, using a discrete-continuous choice framework combined with a definition of products that account for a leverage component.

Third, we contribute to the debate in the banking literature about the link between competition and financial stability, which has been reinvigorated by the 2008 financial crisis (Allen and Gale, 2004; Freixas and Rochet, 2008; Rochet, 2009; Jiang et al., 2016) and the growing literature trying to assess the appropriateness of new macro-prudential regulation and the impact of capital requirements on lending activity(Admati and Hellwig, 2014; Acharya et al., 2014; Behn et al., 2016). On the empirical side, we provide new reduce form evidence on the impact of different macro-prudential regulations on mortgage pricing and originations. More importantly we combine theory and rich microeconomic data by developing and estimating an empirical equilibrium tractable model of the UK mortgage market. We use our estimated model to perform counterfactual policy simulations, along the lines of recent work in other financial industries by Egan et al. (2014), Hastings et al. (2013) and Koijen and Yogo (2016).

Finally, the macro literature has recently studied the impact of macro-prudential regulation in general equilibrium settings and potential heterogeneity in the transmission of these policies (Clerc et al., 2014; Justiniano et al., 2015; Greenwald, 2016). We relate to this body of literature by looking at the differential effects of regulation across different types of borrowers. We take a partial equilibrium approach, but we allow for richer heterogeneity in borrowers' demand and product availability, and we model the interaction between regulation and competitive environment.

The rest of the paper is organized as follows. Section 2 describes the data sources and shows some empirical facts in the UK mortgage market. In section 3 we present reduce form evidence on the impact of macro-prudential regulation. Section 4 develops the demand and supply model. Section 5 describes the identification strategy and the estimation approach. In section 6 we show the results. Section 7 describes the results from the counterfactual exercises and section 7 concludes.

2 Data and facts about the UK mortgage market

In this section we describe our data. First, we discuss the different sources that we combine, the main variables that we use and some limitations. Second, we document some facts about the UK mortgage market, focusing on pricing, originations and performances.

2.1 Data

Our main dataset is the Product Sales Database (PSD henceforth) on residential mortgage originations collected by the Financial Conduct Authority (FCA). The dataset includes the universe of residential mortgage originations by regulated entities since 2005.[1] We observe the main contract characteristics of the loan (rate type, repayment type, initial period, interest rate); the borrowers (income, age) and the property (value, location, size). Moreover we know the identity of the lender issuing the mortgage. We focus on the years 2015 and 2016 in which all lenders reports the information about the price and contract characteristics, that we use in the analysis.

We complement the PSD on mortgage originations with four additional datasets. First, we use an additional source also collected by the FCA with information on mortgage performances. We use a snapshot in June 2015 containing loan-level information on outstanding mortgages from lenders' balance sheets. We match the performance data with the full sample of originations data since 2005. We use the performance data to study average remortgaging and default behaviour at the product and borrower type level. We exploit this information to calibrate our model of mortgage pricing.

Second, we conduct a survey for the lenders adopting Internal Rating Based (IRB) models to collect information on the regulatory risk-weights applied to mortgages.[2] We obtain information for all the main lenders on the risk-weights applied to each loan-to-value band

[1]The FCA Product Sales Data include regulated mortgage contracts only, and therefore exclude other regulated home finance products such as home purchase plans and home reversions, and unregulated products such as second charge lending and buy-to-let mortgages.

[2]The same data on risk weights has been used in Benetton et al. (2016).

in each year. For the lenders adopting the Standardized Approach (SA) we compute the regulatory risk weights.

Third, we collect data on lenders capital requirement, resources and a measure of the cost of funding from an historical regulatory data held by the Bank of England (Harimohan et al., 2016; De Ramon et al., 2016). Last, we download postcode level data on lenders branches in the UK in 2015 from SNL financial and geographical information on the distance between the house of the borrower and the lenders' headquarters from the ONS statistics database.

2.2 Facts

In this section we document some facts of the UK mortgage market and we relate these to the assumptions that we adopt in the modelling framework. First, we describe our product definition and how it fits the UK context. Then we show some patterns in mortgage pricing, originations and performances.

According to Moneyfacts there were about 18.000 products advertised in the UK in 2015. Figure 3 show the snapshot from a popular UK search platform. The price of the loan is given by the initial rate, the reset rate and the fees. The initial interest rate and the fees jointly determine the initial monthly payment. The key characteristics are the provider, the type of mortgage and the maximum loan-to-value. We define a product as a combination of all of the above characteristics.

2.2.1 Pricing

In the UK mortgage market lenders advertise mortgage products via their own network of branches, newspapers, internet and brokers. They set prices and borrowers choose they favourite product from the menu of offered products, that are available to them. Differently from other countries, such as the US and Canada (Allen et al., 2014), in the UK there is no consumer based pricing or negotiation between the borrower and the lender. As a result, the advertised rate is the rate that the borrower pays. Moneyfacts - a popular consumer advice platform - reports:

> *A personal Annual Percentage Rate is what you will pay. For a mortgage this will be the same as the advertised APRC, as with a mortgage you can either have it or you can't. If you can have the mortgage, the rate doesn't change depending on your credit score, which it may do with a credit card or a loan.*

We check this hypothesis in our data. Table 1 shows the results of a regression of the loan-level ("personal") interest rate on product fixed effects and additional controls. Our product definition based on the type of mortgage, the identity of the lender and the loan-to-value segment captures approximately 78% of the variation in the transaction rate. Once we interact the product dummies with time dummies the R^2 increase to 85%. In column (3), we include dummies for the other price that borrower have to pay at originations (fees) and in this way we explain more than 90% of the variation. In column (4) we test the hypothesis that pricing vary with the geographical location of the borrower. Adding dummies for the county of the borrower does not explain the residual variation in the rate. Finally, in column (5) we check if borrowers characteristics affect pricing, by adding borrower level controls (age, income, house value, joint application, employment status). Controlling for the main product attributes, borrower characteristics do not contribute in explaining the variation in prices. Therefore, in the construction of the choice set we use the predicted price from column (2) in table 1.

The remaining variation is due to two possible reasons. First, unobservable product characteristics. Even if we control for the main factors affecting price, there can be some other product characteristics that lenders use to "segment" the market. Second we observe the data when the borrower get the mortgage, but we do not know when exactly the deal was negotiated. Our time dummies capture the variation in the price imperfectly.

We conduct a similar exercise looking at paid initial fees. Our product definition explain "only" about 23% of the loan-level variation in the fees and interacting it with time increase it to 40%. Conditioning on the interest rate, the R^2 increase significantly reaching 67%.

Adding dummy for the county or borrowers' controls increase the explained variation by 3% and 5%, respectively. The larger dispersion that we find in the loan-level fees can by attributable to the same "unobservable" attributes that could affect the rate. Moreover, while the interest rate are not negotiated, there can be more flexibility with respect to fees.

In table 2 we study average interest rate and fee and the product-market level and we decompose the variation into its components. For the interest rate the the most relevant component is the loan-to-value segment. This is confirmed by figure 4, which shows the mean predicted interest rates, from a regression including lenders and mortgage type dummies, but excluding the loan-to-value. We see that the interest rate jumps at the maximum loan-to-values, as already noted in Best et al. (2015). The type of the mortgage explain alone about 20% of the variation in product-level rates, while the lenders dummies account for about 8%. The variation across borrower types accounts for about 15%, thus confirming that lenders price differently depending on the type of borrowers. Finally, the time variation explain about 3% of the variation in the rate. Even if lenders adjust rate every month we only observe a period of one year in which the policy rate was never changed.

Figure 4 explore the heterogeneity in pricing according to interest rate type, panel A, and lender, panel B. Both types show an increasing step-wise schedule with the longer duration mortgage always more expensive that the shorter duration one. This is due to the higher interest rate and refinancing risk embedded in a contract with a longer fixed duration. In panel B of figure 4 we compare a lenders adopting an IRB model with a lender on the Standardized approach. The pricing of the two lenders is fairly similar at low loan-to-value. The IRB lenders increase discountinuously the rate already alove a loan-to-value of 75, while the SA lender increase the rate only above 80, where risk weights start increasing (as in figure 1).

The decomposition of fees reveals a different pattern. Fees does not vary according to the loan-to-value, which only account for about 2% of the variation. The single most important factor in explaining the variation in the fees is the identity of the lender, which alone capture about 30% of the variation in the product-level fees. These patterns suggest the importance to consider jointly interest rates and fees when modelling the pricing decision of lenders.

2.2.2 Originations

We now discuss some features that characterize mortgage choice. Table 3 reports summary statistics for prime residential mortgages originated in 2015-2016. We focus on the three most popular mortgage types offered by the largest 17 lenders, and group other products in the outside option.[3] We further restrict the choice set by including in the outside option products with a market share below 0.25%. The table look at the three characteristics that define a mortgage product: the type (j), the lender (l) and the loan-to-value band (b).

First, we notice that the market is concentrated both in terms of type of mortgage and of lender. The products that we consider are account for more than 87% of originations for first-time-buyers, and almost 80% for home-movers and remortgagers. The popular product is the fixed rate for two years, which account for almost 65% of origination to first-time-buyers and more than 50% to home-movers and remortgagers. When we look at lenders, the so called "big six" account for about 70% of new mortgage originations in 2015. Their share in largest for first-time-buyer and lowest for remortgagers.

In term of the loan-to-value choice there is more dispersion across segments and heterogeneity depending on the borrower type. First-time-buyers take higher loan-to-value mortgages, with about 60% borrowing more than 80% of the value of the house. Home-movers are more evenly distributed across loan-to-values, while more than 55% of remortgagers refinance less than 75% of the value of their property. These patterns are confirmed by figure 5, which also shows that the vast majority of borrowers are concentrated at the maximum loan-to-values. This behaviour is mainly driven by the discrete jumps in interest rates above the different loan-to-value thresholds, as already shown in figure 4.

In the other columns of table 3 we look at price variation across product characteristics and borrower type. On average interest rates are higher for first-time-buyers, taking higher

[3] In Goeree (2008) the outside option captures nonpurchase, purchased of a used PC and purchase of a new PC not in the firms included; Egan et al. (2014) also consider the outside good all the banks outside the top sixteen.

loan-to-values, and lower for remortgagers, who have more equity in the house. Fees are highest for home-movers and lowest for remortgagers.

Both the initial interest rate and the fees are higher for the mortgage with the longer duration across all borrower types. This higher price may reflect the higher cost for the lender, due to refinancing risk (Deng et al., 2000; Rose, 2013). Lenders differ on average along all dimension of pricing. Sometimes a lower average initial rate is associated to a higher fee and vice-versa. Finally, the interest rate increase with the loan-to-value segment, confirming the evidence in figures 4 and this pattern is shared by all borrower types. Fees do not seems to vary in a consistent way across bands.

Finally, in figure 7 we consider the effect of location on mortgage choice. The distance between the borrower and the lender continuous to play an important role even in modern lending markets (Becker, 2007; Scharfstein and Sunderam, 2014). Even if most lenders operate on the whole UK market, heterogeneity in the network of large lenders and in the presence of smaller building society can shape borrowers' choices. Panel A of figure 7 shows that the market share of a lender decline with the distance from the historical headquarter. Panel B of figure 7 captures the impact of the local presence of branches on market shares. Accounting for the effect of these features in the demand model is important to capture for factors that can affect the elasticity (e.g. limited substitution due to local shopping).

2.2.3 Performances

In table 4 we show some patterns in mortgage performances at the product level. The key risks in mortgage pricing according to the literature are the refinancing and the default risk (Schwartz and Torous, 1989; Campbell and Cocco, 2015). We consider them in table 4 in turn.

We capture the default risk by looking at mortgages originated since 2005, that are in arrears in 2015. The arrears columns of table 4 report the fraction of outstanding mortgages in 2015 that are in late payment or default out of total number mortgages in the lender's balance sheet for the specific product. The average fraction of arrears is around 2%, which is in line with aggregate data for the industry and confirm the relative low default risk for mortgages. There is however heterogeneity along two dimensions of interest for our analysis.

First, the fraction of loan in arrears is lower for the big six lenders, at about 2%, than for the challengers bank and the other large building societies, with approximately 3% and 2.5%, respectively. One explanation for this fact is that incumbent lenders focus on lower-risk mortgages (e.g. lower loan-to-values), as we provide evidence in table 5. Moreover, there can be negative selection for challengers banks if safest borrowers first approach an incumbent bank and then, if rejected, turn to a challenger one.

Second, the fraction of arrears increase monotonically with the loan-to-value. This pattern is reflected in the pricing schedule from figure 4. The increase in arrears with the loan-to-value can be due to both adverse selection, with more risky borrowers choosing higher loan-to-value mortgages, and more hazard, because the higher rate induce more defaults. Even if we cannot distinguish between these different sources, we consider in the pricing model how lenders account for asymmetric information and default risk when setting mortgage prices.

We now discuss refinancing risk. We consider the fraction of outstanding mortgages in 2016 that are on a standard variable rate (SVR) out of the total mortgages in the lender's balance sheet for the specific product. In the UK mortgage market the standard variable rate is the reset rate, that borrowers pay at the end of the initial fixed or discounted period. The refinancing variable is defined as one minus the share paying the SVR.

From table 4 we see that in 2016 more than 75% refinance their mortgage before the switch to the SVR. This number is high and reveal that the refinancing risk is quantitatively more important than the default risk. The refinancing risk is slightly higher for home-movers, and smaller for remortgagers. One reason for this can be that the outstanding balance for remortgagers is usually smaller, so that paying a higher rate has a relative smaller impact.

The fraction of borrower refinancing is always lower for the big six banks than for challenger banks. This feature is consistent with the largest banks having an existing loan-book of customers accumulated over the years. Finally, the share of borrower refinancing decrease monotonically with loan-to-values above 75%. This fact is consistent with the view that it may be harder for borrower with little equity on their property to refinance it.

In table 4 we also show the standard variable rate (SVR) that borrowers are paying. The standard variable rate is always above 4%. Challengers lenders and building societies have an average higher SVR, while the SVR does not seem to vary across loan-to-value bands, in a way similar to the origination rate. A comparison between the SVR in table 4 and the rate at origination in table 3 show clearly that the former is always (much) larger that the latter. This difference justify the strong incentive in the UK mortgage market to refinance the mortgage at the end of the initial period. Best et al. (2015) show indeed that the vast majority of borrowers refinance their mortgage at the time when the initial period ends.

3 Reduce form evidence

In this section we present reduce form evidence on the implication of macro-prudential regulation in the mortgage market. We propose to test. First, we look at the impact of risk-adjusted capital requirements on mortgage prices. Second, we study the impact of a recommendation on LTI limits on mortgage originations.

3.1 Risk-weighted capital requirements

In this section we provide some reduce form evidence on the impact of capital requirements on lending. Capital requirement affect the cost of lending and can then be pass-on to mortgage rate. In this section, we look directly at the relation between mortgages interest rates, along the lines of Benetton et al. (2016). Moreover, we show some evidence of its interaction with competition. Our model allow the decompose the effect of capital requirements on estimated cost and how the pass-through is affected by the competitive environment.

Table 5 presents some evidence on the transmission channel, by looking at heterogeneity across LTV (low and high), lender type (leader vs challenger) and capital regulation models (IRB vs SA).

First, we look at the risk-weights as a cost to originate a mortgage. The average risk-weight is about 13% for mortgages with an LTV below 75, while 10% higher for mortgage above 75%. The leader lender has lower risk-weights both at low and at high LTV than the challenger lender, but the difference is largest at low LTV. This difference is driven by the capital regulation model adopted. The challenger lender has a standardized approach, with higher risk-weights at low LTV, while the leader lender has an internal model (see figure 1). Even within lenders adopting an internal model, we observe variation in the risk-weights. The gap between the IRB lender with the lowers and highest risk weights is about 7% at low LTV and 22% at high LTV.

Second, we look at prices, as measured by the interest rate. Table 5 shows that the average interest rate on mortgages below 75% is about 2.3%, increasing to 3.1 % for mortgages with an LTV above 75%.

Third, we study the impact on quantities. We look both at portfolio shares and market shares. At the market level both portfolio shares and market shares are fairly balances between high and low LTV. However, the leader lender has a higher portfolio share in low LTV and a relative larger market share in low LTV, than the challenger lender. When we look at the capital requirement model, IRB lenders have a portfolio share in line with the market average. The SA lender portfolio is instead tilted toward high LTV lending, which account for almost 65%. The distribution of portfolio shares in different LTV is confirmed when we look at market shares. IRB lender have similar market shares in low and high LTV, while the SA lender, has overall lower market shares, but relative less at low LTV.

We explore the relation between capital requirements and interest rate, with the following fixed effect model:

$$r_{jlb}^{kt} = \beta CapReq_{lb}^{t} + X_{jlb} + \gamma^{kt} + \gamma_{l} + \epsilon_{jlb}^{kt} \quad (1)$$

where r_{jlb}^{kt} is the interest rate in month t for borrower type k offered by lender l for product j at LTV band b; $CapReq_{lb}^{t}$ is the risk-adjusted capital requirement; X_{jlb} are product level controls; γ^{kt} and γ_l are borrower type, time and lender fixed effects. The coefficient of interest is β, which captures the reduce form effect of risk-adjusted capital requirements on mortgage rates.

Table 6 shows the results. We find that 1% higher risk-weight lead to a 0.8 basis point higher interest rate. In column (2) we show our favourite specification with the full set of fixed effects. In this case control for time invariant differences across lenders and for time varying common factors affecting pricing. We find that 1% higher risk-weight lead to a 0.7 basis point higher interest rate. In the remaining column of table 6 we run model **??** separately for the different borrower types. We find a strong and significant effect of risk-adjusted capital requirements for first-time-buyers. A 1% higher risk-weights translate into a 2.5 basis point higher mortgage rate. The effect is lower, but significant for home-movers. In this case, a 1% higher risk-weights translate into a 1.6 basis point higher mortgage rate. The effect is non different from zero for remortgagers.

The controls have the expected sign. Mortgages with a longer duration of the initial period have a higher interest rate, to compensate for the additional refinancing risk. Mortgages with with a higher downpayment have lower interest rate, because of the lower default risk.

3.2 Loan-to-income limits

In this section we describe our second test of the effect of macro-prudential regulation. We exploit exogenous variation coming from a recommendation by the Financial Policy Committee (FPC) on loan to income ratios. The main statement says:

> *The Prudential Regulation Authority (PRA) and the Financial Conduct Authority (FCA) should ensure that mortgage lenders do not extend more than 15% of their total number of new residential mortgages at loan to income ratios at or greater than 4.5. This recommendation applies to all lenders which extend residential mortgage lending in excess of £million per annum. The recommendation should be implemented as soon as is practicable.*

We design an identification strategy based on a measure of exposure to the FPC recommendation. Ideally we would like to divide the sample on the basis of the exogenous threshold established in the recommendation. However, all large lenders in the UK are above the threshold and are therefore affected by it. We develop an alternative strategy creating a measure of exposure to the recommendation. We divide lenders based on their fraction of mortgages with an LTI above 4.5 before the date of the recommendation. We define as "treated" the lenders with a fraction of LTI above 4.5 above the median and estimate the following difference in difference model:

$$Share_l^{kt} = \beta_1 Treatment_l + \beta_2 Post^t + \beta_{12} Treatment_l \times Post^t + \epsilon_l^{kt} \tag{2}$$

where $Share_l^{kt}$ is the share of mortgages offered by lender l with an LTI above 4.5 in month t for borrower type k; $Treatment_l$ is a dummy equal to one if the lender is above the median market share of high LTI before the introduction of the limit; $Post_t$ is a dummy equal to one from July 2014 onwards. The coefficient of interest is β_{12}, which captures the reduce form effect of LTI limits on LTI originations.

Table 7 shows the results. In column (1) we show the baseline difference in difference model. We find that treated lenders reduce their fraction of high LTI mortgages by almost 4% relative to control lenders. In column (2) we add a full set of time and lender fixed effects. The results are still significant at the 5% level and the magnitude is unaffected. Finally, in the remaining columns of table 7 we explore heterogeneity depending on the type of borrowers. We find that the impact of the FPC recommendation on LTI limits is strongest for first-time-buyers, lower for home-movers and not significant for remortgagers.

4 A model of mortgage demand and pricing

In this section we build a model of mortgage demand and pricing. First, we specify borrower utility as a function of product characteristics and leverage and derive demand at the product level. Then, we develop a pricing equation that account for the key features of the UK mortgage market.

4.1 Utility and demand

In each period t there are I^{kt} borrowers of type k indexed by i, choosing a mortgage to buy or refinance a house. We take as given the choice of the value of the house and its location and focus on the financing choice. The borrower financing choice two simultaneous decisions: which product to buy, among the lenders and types of mortgages available to him (product choice) and how much to borrow, given his preferences and budget constraint (leverage choice). The choice of their product and leverage is affected by several factors. We follow the characteristics approach (Lancaster, 1979) and assume that each mortgage can be represented as a bundle of attributes and that borrowers have preferences for these attributes. Building on Dubin and McFadden (1984), we develop a discrete-continuous conditional logit model to account for the joint decision of the product, the leverage and the application decision. We improve with respect to previous studies that only consider a "representative" product for each provider and model only the choice across providers (Hastings et al., 2013; Crawford et al., 2015; Koijen and Yogo, 2016).

We assume that the conditional loan demand function takes the linear form:

$$q^i = \beta_0 + \alpha^i_q r^{ikt}_{jlb} + \beta^i D^i + \varepsilon^i \tag{3}$$

Where q^i is the loan demanded by borrower i, r^{ikt}_{jlb} is the interest rate chosen by borrower i for LTV band b type j and lender l in period t for borrower type k; D^i are borrower i demographics; ε^i captures unobservable differences across borrowers in the demand for loans. The key parameter of interest is the elasticity of loan demand with respect to the interest rate, which we allow to vary across borrowers (α^i_q). The loan demand function from equation 3 can be obtained using Roy's identity on the borrower indirect utility function.

The full utility indirect utility for borrower i taking product jlb is given by:

$$V^i_{jlb} = \bar{V}^i_{jlb} + \varepsilon^i_{jlb} = \alpha^i_d Down_b + \alpha^i_r r^{kt}_{jlb} + \alpha^i_f fee^{kt}_{jlb} + \beta^i X_{jl} + \lambda^i App^i_l + \xi^{kt}_{jlb} + \varepsilon^i_{jlb} \quad (4)$$

Where $Down_b$ denotes the minimum down-payment in band b; r^{kt}_{jlb} and fee^{kt}_{jlb} are the interest rate and the fees for band b type j and lender l in period t for borrower type k; X_{jl} capture mortgage characteristics (e.g. the length of the fix period, brand); App^i_l is the number of branches in location where i lives; ξ^{kt}_{jlb} denotes unobservable characteristics (e.g. advertising, payment holiday) that affect the utility of all borrowers in a market for a certain product; and ε^i_{jlb} is an extreme-value error.

The key parameters of interest are the elasticity with respect to the minimum down-payment and the interest rate, α^i_d and α^i_r respectively. This parameter captures the leverage decision. This choice follows a standard intertemporal trade off between consumption today and consumption tomorrow (Brueckner, 1994). A higher leverage (more consumption today) implies a higher repayment burden in the future, thus lowering consumption via a larger monthly payment. We enrich the standard framework to account for the non-linearities in the pricing schedules described in section 2, by allowing the initial interest rate to depend on the loan to value chosen. From figure 4 we see that lenders set a price that increase discontinuously at some maximum loan-to-value thresholds.

We assume that all borrowers face the same prices when they buy a mortgage product. This assumption is reasonable, since in the UK mortgage market lenders set national prices, that do not vary geographically or on the base of other borrower demographics (See section 2.2). Even if prices are exogenous from the point of view of the borrowers, there can be however some unobservable (to the econometrician) product characteristics that are correlated with price and affect the utility of the borrower. As an example think to a lender introducing for high loan-to-value products a payment holiday option and raising the price. Our estimation of the price coefficient will be biased because borrowers are possibly compensating a higher price with other product characteristics. We explain how we deal with possible endogeneity in prices in section 5.3.

The variables in X_{jl} allow us to include a dimension of horizontal differentiation at the type and brand level. The type is defined jointly by the repayment (e.g. capital and interest, interest only) and the rate type (fix for 2 years, fix for 5 years). The brand is captured by the lender issuing the mortgage. This allow us to capture in a more realistic way substitution patterns across products.

We include a second dimension of differentiation at the transaction level, that varies jointly across borrowers and lenders (App_l^i). In reality borrowers search for mortgage products and apply via branches, intermediaries and online comparison website. The application process is long and can be very costly. Moreover borrower may be more likely to apply for a mortgage to banks where they have a pre-existing relation (e.g. a current account). Finally, a rejection can be costly for the borrowers future access to credit, because it affects his credit score. Ideally we would like to observe the true borrower choice set when applying for mortgages, but this information is not available in most settings.[4] We account for these features by modelling the borrowers' costs associated to the application for mortgages and the formation of the choice set.

We add the distance of borrower house from the head-quarter of the lender issuing product and the number of branches of the group in the county of borrowers' house. By adding these variables in the application cost we allow for two possible explanations. On the one hand, lower distance between the borrower and the "lender" and more branches can make the lender more salient to the borrower, by increasing the probability that the borrower will consider it. Moreover in the absence of data on borrowers assets, the distance can proxy for pre-existing relations between the borrower and the lender (e.g. current account). On the other hand, less distance and higher branch presence can increase the utility for borrowers, because they generate spatial differentiation. For example, a large branch presence allow the borrower to walk in a branch when needed, thus lowering transaction costs.

We allow the preference parameters to vary with observable borrowers characteristics

[4]See Basten and Koch (2015) and Michelangeli and Sette (2016) among possible exceptions.

(D^i) . Among the demographics we include the gross income and the age of the borrower. We also allow for unobservable heterogeneity in the elasticities. This allow us to generate more realistic substitution patterns across products. We can therefore rewrite equation 4, as follows:

$$V^i_{jlb} = \underbrace{\bar{\alpha}_d Down_b + \bar{\alpha}_r r^{kt}_{jlb} + \bar{\alpha}_f fee^{kt}_{jlb} + \bar{\beta} X_{jl} + \xi^{kt}_{jlb}}_{\delta^{kt}_{jlb}} + \underbrace{[Down_b;\ r^{kt}_{jlb}; fee^{kt}_{jlb};\ X_{jl}](\theta D^i + \sigma \nu^i) + \lambda^i App^i_l}_{\mu^i_{jlb}} + \varepsilon^i_{jlb} \tag{5}$$

Where δ^{kt}_{jlb} represents the mean utility from product jlb; μ^i_{jlb} captures observable (D^i) and unobservable (ν^i) idiosyncratic taste for product attributes and borrower specific application costs.

We adopt the standard conditional logit model framework by imposing a restriction to the choice set of the borrower. On the one hand, a borrower may not be able to borrow up to the desired leverage, due to to supply side restrictions (e.g. a loan-to-income (LTI) limit). On the other hand, due to liquidity constraint the borrower may not have the liquidity to increase the down-payment and consider products at lower loan-to-value bands. Both types of constraints will restrict the choice set of the lenders in terms of loan-to-value bands accessible among the full set available in the market. The borrower maximize utility by choosing his preferred product, subject to an affordability constraint, specified as follow:

$$\begin{aligned} &\max_{jlb \in JLB^i} V^i_{jlb} = \delta^{kt}_{jlb} + \mu^i_{jlb} + \varepsilon^i_{jlb} \\ &\qquad with\ JLB^i \subseteq JLB \qquad\qquad\qquad\qquad \textit{Affordability constraint} \\ &\qquad\quad jlb \in JLB^i\ if\ b = b^{chosen} - 1, b^{chosen}, b^{chosen} + 1 \end{aligned}$$

Where JLB is the number of all products available in a given market. In the standard case the borrower has access to all products, so that $JLB^i \equiv JLB$. In the case of affordability constraints we restrict the choice set of the borrower to products in the chosen loan-to-value band and only above and below. We discuss in detail the construction of the borrower specific choice set in section 5.1.

Before moving to the supply side, some remarks are in order. First, we use the initial interest rate at origination. That is we assume that borrowers expect future interest rates to reflect current interest rates. This assumption holds for fixed rate mortgages until the end of the initial period and is reasonable for variable rate mortgages, given the short horizon before remortgaging.

Second, we rule out strategic default. This assumption is reasonable since in the UK mortgage market all loans are recourse, which means that borrowers are responsible for payment even beyond the value of the house. Defaults on mortgages are therefore very costly and the empirical evidence from survey data confirm that defaults are the consequence of inability to meet the payment, rather than a choice.[5]

Third, we do not model the "participation decision" to take a mortgage versus the alternative of buying outright, as the vast majority of house purchases in the UK involves a mortgage[6]

Last, we develop a static model, which does not allow us to study issues related to the timing of the purchase. This will complicates the analysis, given that the timing will be affected by many additional factors not limited to the mortgage (e.g. housing market). Morever, our interest is about the composition of mortgage choice across lenders, types and loan-to-value, rather than about the number of mortgage originations. A a static model will be able to capture the key trade-offs.

[5]The possibility of borrowers defaulting on loans is included in lenders' optimal pricing strategy.

[6]A more interesting and empirically relevant extensive "participation decision" will involve the choice of buying a house versus the alternative of renting. Due to data availability we cannot consider this margin.

4.2 Pricing

In this section we study the pricing problem of lenders when they set mortgage prices. In each period t there are L^t lenders that maximize (expected) profits by setting a price schedule for each product they offer. Our focus will be on acquisition pricing: initial rate and up-front fees; while we consider indirectly retention pricing, via the reset rate, including it as a product characteristic[7]. As already mentioned in section 2.2.3 the vast majority of borrowers refinance their mortgage at the time their initial rate expires. As a result, the initial rate and fees is likely to be a major source of revenues for lenders. However, a fraction of borrowers may not refinance at all or not exactly at the end of the initial period. This will make the reset rate a potentially profitable source of revenues for lenders, given that the reset rates are always much higher than the introductory rates (compare tables 3 and 4).

We assume that lenders compete on prices in a differentiated product market. Unlike other retail products, such as cars, we cannot simply take the difference between the price (interest rate) and the unit cost to study the incremental profitability from an additional sale. The key difference in the case of loan is that the profitability from a sale is not realized when the sale takes place but over time. We take this explicitly into account in the lender maximization problems and exploit some features of the UK mortgage market to make the model tractable and take it to the data.

The source of revenue for the lenders are the initial fees and the net interest income from the monthly payment. The present value of net interest income from a risk-free mortgage with fixed rate r until maturity is given by:

$$PV(q,r,T) = q\sum_{k=1}^{T}\left[\frac{r(1+r)^T}{(1+r)^T-1} - \frac{c(1+c)^T}{(1+c)^T-1}\right] \tag{6}$$

Where r is the initial interest rate, T is the maturity, q is the quantity borrowed and c is the rate at which the lender borrow the money (e.g. the policy rate plus a spread),

[7]In the period we analyse there is almost no variation over time in the standard variable rate, so that it is captured by the lender dummies

which we assume to be constant over time. We now adjust 6 to adapt it to the setting we are analysing. First, given the high level of refinancing at the end of the initial period it is unreasonable to assume that lenders compute the present value as if all mortgages are held until maturity. We assume that lenders consider that a fraction of borrowers will remortgage at the end of the initial period, while the remaining will pay the reset rate until maturity. [8] The present value adjusted for remortgage risk is given by:

$$PV(q,r,R,t,T) = q\sum_{k=1}^{t}\left[\frac{r(1+r)^T}{(1+r)^T-1} - \frac{c(1+c)^T}{(1+c)^T-1}\right] + \gamma b\sum_{k=t+1}^{T}\left[\frac{R(1+R)^{T-t}}{(1+R)^{T-t}-1} - \frac{c(1+c)^{T-t}}{(1+c)^{T-t}-1}\right] \quad (7)$$

Where R is the reset rate, t is the length of the initial period and b the remaining balance at the end of the initial period[9].

Second, we allow for the possibility that borrower can default. This raise the cost of the lender to issue a mortgage. We follow Phillips (2013) and define $s_k = \prod_{r=1}^{k}(1-d_r)$ the probability that borrower will make payment k, where d_r is the probability of default in period r. Accounting for both default and prepayment risk, the present value of net interest income is given by:

$$PV(q,r,R,t,T) = q\sum_{k=1}^{t}\left[\frac{s_k r(1+r)^T}{(1+r)^T-1} - \frac{c(1+c)^T}{(1+c)^T-1}\right] + \gamma b\sum_{k=t+1}^{T}\left[\frac{s_k R(1+R)^{T-t}}{(1+R)^{T-t}-1} - \frac{c(1+c)^{T-t}}{(1+c)^{T-t}-1}\right] \quad (8)$$

For large values of the maturity T we can approximate 8 as:

[8] Even if borrowers can refinance the mortgage in any month, we capture this risk in a simpler way by allowing one remortgaging opportunity at the end of the initial period. This is consistent with previous evidence, showing that the vast majority of borrowers that remortgage do in a window around the end of the initial period (Best et al., 2015).

[9] Note that equation 7 nests the simpler mortgage contract with fixed rate r until maturity

$$PV(q,r,R,t,T) \approx \overbrace{q\left[t(r-c)+\gamma(T-t)(R-c)\right]}^{\text{“Risk-free” return}} +$$
$$\underbrace{-(1-s_t)\frac{qr\sum_{k=1}^{t}(1-s_k)}{1-s_t} - \gamma(1-s_T)\frac{qR\sum_{k=t+1}^{T}(1-s_k)}{1-s_T}}_{\text{Probability of Default (PD)} \times \text{Loss Given Default (LGD)}} \tag{9}$$

The first line capture the return, that is free from default risk, but already account for the refinancing risk. The return from a non-defaulting borrower that refinance the mortgage at the end of the initial period is given by: $qt(r-c)$; while the return from a borrower that pays the mortgage until maturity is approximately: $q\left[t(r-c)+(T-t)(R-c)\right]$. The second line captures the default risk, which can materialize both during the initial period and afterwards. The probability that the loan defaults before (after) the end of the initial period is given by $1-s_t$ $(1-s_T)$ and the loss given default is equal to $\frac{qr\sum_{k=1}^{t}(1-s_k)}{1-s_t}$ $(\frac{qR\sum_{k=t+1}^{T}(1-s_k)}{1-s_T})$.

The lender setting the interest rate does not forecast the probability of default in each period, but consider an average proability of default (as in Crawford et al. (2015)). We assume a constant default probability in each period $d_r = d \; \forall r = 1, ..., T$ [10]. In this case the net return given by 9 simplifies to:

$$\begin{aligned} PV(q,r,R,t,T) &\approx q\left[t(r-c)+\gamma(T-t)(R-c)\right] - (1-s)q\left[tr+\gamma(T-t)R\right] = \\ & q\left[tr+\gamma(T-t)R\right]s - q\left[tc+\gamma(T-t)c\right] \end{aligned} \tag{10}$$

Lenders decide in each period t initial rate and fee for each product j and each band b they offer to a specific borrower type k, taking as given the prices set from the competitors. Given the demand system and the approximation of the net revenue from interest payment 10 we can write the problem of the lender as:

[10] In the data we do not observe at each point in time the probability that borrowers make each payment in each period, but only an average probability of default.

$$\max_{r,f} \Pi_l(r, f; \theta^i) = \sum_{j,b \in J_l} \Pi^{kt}_{jlb}(r^{kt}_{jlb}, f^{kt}_{jlb}; \theta^i) =$$

$$\sum_{j,b \in J_l} \sum_{i \in I^{kt}} q^i_{jlb}(r^{kt}_{jlb}, f^{kt}_{jlb}, X_{jlb}, r^{kt}_{-jlb}, f^{kt}_{-jlb}, X_{-jlb}; \theta^i) \left[f^{kt}_{jlb} + PV^i_{jlb} \right] \tag{11}$$

Where θ^i collects all the demand paramters and we sum over the expected demand q^i_{jlb} coming from the product and quantity choice of all borrowers in period t of type k. If we assume that the initial interest rate does not affect the probability of remortgaging $\frac{\partial \gamma}{\partial r} = 0$, we can derive the optimal pricing rule for product j. This is given by:

$$r^* = \underbrace{\frac{c(t + \gamma(T - t))}{t\left(s + \frac{\frac{\partial s}{\partial r} q}{\frac{\partial q}{\partial r}}\right)}}_{\text{Effective marginal cost}} - \underbrace{\frac{\frac{sq}{\frac{\partial q}{\partial r}}}{s + \frac{\frac{\partial s}{\partial r} q}{\frac{\partial q}{\partial r}}}}_{\text{Full mark-up}} - \underbrace{\frac{f^*}{t\left(s + \frac{\frac{\partial s}{\partial r} q}{\frac{\partial q}{\partial r}}\right)}}_{\text{Fees effect}} - \gamma \underbrace{\frac{R(T - t)}{t}}_{\text{“Add-on” effect}} \tag{12}$$

Note that if there is no adverse selection and the mortgage bears no default risk ($\frac{\partial s}{\partial r} = 0$ and $s = 1$), fees are zero ($f = 0$) and all borrowers remortgage at the end of initial period ($\gamma = 0$), then 12 collapse to the standard mark-up pricing formula. In the appendix we derive a similar formula for the up-front fees.

Equation 12 characterize the optimal interest rate for lenders in the case of no constraints except the competitive pressure of alternative products embedded in the elasticity of demand. In reality when lenders set prices they account for several regulatory constraint. We focus on two macro-prudential tools in this paper. First, we are interested in the impact of risk-adjusted capital requirement on mortgage pricing and lending volumes. To account for it we add a risk-weight capital constraint to the bank optimization problem. Even if lenders' balance sheet have other assets than mortgages we assume that when firm price mortgages they behave so that they can be constraint by the capital requirement. Second, we study a recent introduced limits on the fraction of mortgage with a loan-to-income (LTI) above 4.5. To study this second macro-prudential intervention we add a quota to the products above the limits, along the line of Goldberg (1995) for cars' import. The problem of the constrained lenders therefore become:

$$
\begin{aligned}
\max_{r,f} \Pi_l(r, f; \theta^i) = \sum_{j,b \in J_l} \Pi^{kt}_{jlb}(r^{kt}_{jlb}, f^{kt}_{jlb}; \theta^i) & \\
s.t. \;\; \underline{\mathrm{K}}^t_l \sum_{j,b \in J_l} q^{kt}_{jlb} \rho_{lb} \leq K^t_l & \qquad \textit{Capital constraint} \\
\frac{\sum_{j,b \in J_l} q^{kt}_{jlb} \mathbb{I}[LTI > 4.5]}{\sum_{j,b \in J_l} q^{kt}_{jlb}} \leq 0.15 & \qquad \textit{LTI constraint}
\end{aligned}
$$

Where $q^{kt}_{jlb} = \sum_{i \in I^{kt}} q^i_{jlb}$ is the total demand for product jlb in market kt; K^t_l is the time varying capital resources by lender; $\underline{\mathrm{K}}^t_l$ is the lender specific minimum capital requirement; and ρ_{lb} are the risk-weights. The latter can vary both across lenders, due to different risk-based models and across loan-to-value segment as we have shown in figure 1. The Lagrangian multiplier associated with the constraints represent the shadow value of macro-prudential regulation.

The initial interest rate increase with the capital requirement and the risk-weights. The equilibrium in the market is characterized by lenders optimal pricing subject to the macro-prudential constraints. We are currently working to characterize the equilibrium in both fees and interest rate with both macro-prudential tools potentially binding.

5 Identification strategy

In this section we present our identification strategy. First, we describe how we build borrowers' choice sets, in the presence of unobservable choice sets and affordability criteria for accepting borrowers' applications. Second, we describe the econometric model and estimation approach. Third, we discuss the variation we use for identification and our supply-side instruments.

5.1 Affordability criteria and choice set

We estimate the model separately for three borrower types: first-time-buyers (FTB), home movers (HM) and remortgagers (RMGT). These three different types represent separate markets, in which lenders offer different products. In the top part of figure 3 we show the first page when searching for mortgage products in one of the most popular UK search websites. The first information borrowers need to enter is the 'type' of mortgage they are looking for, which depends on the purpose of the transaction: refinancing an existing property (remortgagers), buying a property (home-movers), buying a property for the first time (first-time-buyer). We consider the purpose of the transaction as predetermined and focus only on owner occupied mortgages, thus excluding buy to let.

Given the borrower type, we need to determine the products in his choice set. We proceed in two steps. First, we classify borrowers into cells based on borrowers' type, income and months, when they receive the loan. In this way we construct a "large" choice set for borrower i, that includes all products sold in the cell c to which borrower i belongs. This first step leans to an average number of products in each cell of about 300. A major drawback of the approach to define the choice set so far is that we can include products that are not in borrower i choice set (Goeree, 2008; Gaynor et al., 2012). On the one hand, consider the case in which borrower i in cell c takes a product with a 90% maximum loan-to-value and there is a borrower j in the same cell taking a product with a 75% maximum loan-to-value. The 75% product would appear in borrower i choice set, even if it is unlikely that it would have been truly considered by borrower i, due to for example to inability to make the necessary down-payment to get any 75% product. On the other hand, we can imagine the symmetric case in which borrower i take the maximum 75% loan-to-value product, when another borrower k in the same cell takes the maximum 90% one. The latter product may not have been in borrower i choice set for at least two reason. First, a maximum loan-to-income limit can apply so that even if both i and k belong to the same income bracket the maximum loan-to-value at which they shop can be different due to the different house that they want to buy. Second, even if the 90% product was in theory available to borrower i, he may not have considered it given that he could get better deals shopping at lower maximum loan-to-values.

We address this issues in a second step, in which we refine the construction of the borrower specific choice set. We further restrict the number of products considered by borrower i by limiting the choice set to all products in borrower i cell with a maximum loan-to-value equal to the one chosen by i or in the band just above and below [11]. In this way we allow the borrower to shop locally in terms of the down-payment decision, thus allowing for the bunching behaviour from figure 5. After this second step we reduce the average number of products in the borrower specific choice sets to around 100. This number is still large compared to the number of products that borrowers seem to seriously consider according to survey data, but it can be a more realistic estimate of the product truly available and potentially considered by the borrower.

Given the national nature of the market we do not exogenously restrict the choice set based on geographical location. Our analysis focus on the largest lenders, which have their portfolio widespread across the UK. Moreover, even products from smaller lenders, with a more local business model, can be sold nationally via internet, phone and brokers. Ruling out products from borrowers' choice sets based on their relative location from the lenders and their branches seem to be somewhat extreme and unrealistic in a market such as the UK. However, we allow for geography to play a role by affecting the application cost.

5.2 Estimation

We estimate the demand and supply side separately. Our model predicts for every borrower mortgage demand as a function of observable borrower characteristics, random preferences, products attributes and a vector of parameters to be estimated. If we assume that ε^i_{jlb} in equation 5 is extreme value, the probability that borrower i borrower from lender l

[11] As a robustness we perform all our analysis when we stop at the first step of the choice set definition, thus enlarging the choice set.

mortgage type j with a maximum loan-to-value b is given by:

$$Pr^i_{jlb} = \frac{exp(\bar{V}^i_{jlb}(\theta))}{\sum_{j'l'b' \in JLB^i} exp(\bar{V}^i_{j'l'b'}(\theta))} \tag{13}$$

We adopt a two-step methods based on simulated maximum likelihood as in Train (2009). In the first step we estimate a conditional logit model to estimate individual specific parameters in μ^i_{jlb} and the product-market specific constants (δ^{kt}_{jlb}), using the contraction method (Berry, 1994). In the second step, we estimate a linear model with the mean values as the dependent variable and the product characteristics as the explanatory variables:

$$\delta^{kt}_{jlb} = \bar{\alpha}_d Down_b + \bar{\alpha}_r r^{kt}_{jlb} + \bar{\alpha}_f f^{kt}_{jlb} + \bar{\beta} X_{jl} + \xi^{kt}_{jlb} \tag{14}$$

in which we recover the mean elasticities, brand valuations and preferences for product attributes. We discuss how we deal with endogeneity concern in the second step in section 5.3. Following Dubin and McFadden (1984) we allow the error in the continuous choice of the loan (3) and the discrete choice (4) to be correlated. This correlation can be due to several reasons affecting the joint decision of the mortgage product and the loan size. A borrower with a high unobservable taste for housing (high ε^i) may be willing to take a higher LTV mortgage with certain characteristics (e.g. variable rate). Therefore the conditional distribution of ε^i for borrower that takes product jlb may be different from the unconditional distribution. We address this selection problem by including in the regression of the loan quantity a correction term:

$$q^i = \beta_0 + \alpha^i_q r^{ikt}_{jlb} + \beta^i D^i + \underbrace{\sum_{j'l'b' \neq jlb} \gamma_{j'l'b'} \left[Pr^i_{j'l'b'} \frac{\ln(Pr^i_{j'l'b'})}{1 - Pr^i_{j'l'b'}} + ln(Pr^i_{jlb}) \right]}_{\text{Correction term}} + \omega^i \tag{15}$$

Where $Pr^i_{j'l'b'}$ and Pr^i_{jlb} are the estimated probabilities from 13.

The estimation of the supply side parameters is based on the optimal pricing formula derived in section 4.2. Using the estimated parameters from the demand side, additional information from lenders' balance sheets and equation 12 we can estimate the effective marginal cost. We then regress the estimated cost on products attribute, lenders funding cost and regulatory limits. In this way we obtain a two-step estimator of the cost parameters. We run the following linear specification to estimate the cost parameters:

$$Fullcost_{jlb}^{kt} = \eta_X X_{jlb} + \eta_c c_{jl}^t + \eta_R \underline{\mathrm{K}}_l^t \rho_{lb} \tag{16}$$

Where c_{jl}^t is the marginal borrowing cost for lender l when issuing mortgage j in period t, given by the risk-free rate (e.g. policy rate or libor) plus a lender-specific spread and the cost to swap the fixed rate into a variable rate.

The parameter η_R associated to the risk-weighted capital requirement identify the average shadow value of macro-prudential regulations for the system. We explore further the heterogeneity in the shadow value of relaxing the capital constraint across lenders. Given that the capital requirement vary across products offered by the same lender, due to the risk-weights adjustment, we can control for lender average differences in cost adding lender fixed effects an identify the shadow value of relaxing the constraint only with variation within lender. We think that our identification strategy for the shadow value of regulation is more compelling that one based only on the variation across lenders, as other unobservable confounding factors can be correlated with average differences across lenders.

5.3 Identification and instruments

In this section we deal with the classic endogeneity concern coming from the unobservable attributes affecting demand and the simultaneity problem. First, we consider exogenous the time-invariant attributes (X_{jlb}) and the variable affecting the application decision (App_l^i). The key endogenous variables are the time-varying interest rate and fee. We tackle the endogeneity in prices in two ways. First, we include dummies for the brands. In this way we control non-parametrically for time-invariant average unobservable "quality" of brands and identify the price elasticity from the joint variation across type, band and time within lender.

Even in this setting differences in the utility that borrowers derive from a given product can be due to unobservable (to the econometrician) attributes that can be correlated with prices.

The use of individual data does not solve the endogeneity problem completely. On the one hand, the price setting decision of the lender can be taken as exogenous from the point of view of the borrower and we can also rule our reverse causality from the "atomistic" individual borrower to the lender. On the other hand, unobservable attributes at the product level can be correlated with prices, thus biasing our result. Imagine a lender that offer a larger cash-back for a specific deal and at the same time increase the interest rate on that product. The cash-back offer is not observable, thus entering the error term (ξ_{jlb}^{kt}) and is corrected with the price for that product in that market, such that $E\left[\xi_{jlb}^{kt}|Down_b, X_{jl}, r_{jlb}^{kt}\right] \neq 0$). We may see borrower still buying that product and mistakenly conclude that they are not responding to the price, while the effect of the higher price has been countervailed by the cash-back feature. We instrument using exogenous supply side shifters at the product level. Our instruments are based on differential regulatory treatment that affect the cost for lenders of issuing a particular product. Differently from previous papers that develop supply side instruments at the firm level (Egan et al., 2014; Koijen and Yogo, 2016), we exploit some institutional features of the regulation in place to develop a supply-side instrument at the product level. As we explained in the introduction in the UK since Basel II lenders have to apply risk-weights that vary depending on their internal model (cross-lender variation) and on the loan-to-value of the loan (cross-segment variation). Figure 1 show the two different dimension of variation of our instrument. We also include the regulatory capital requirement that vary across lenders and over time as a second supply-side shifter.

The identification assumption for the demand parameters is:

$$E\left[\xi_{jlb}^{kt}|Down_b, X_{jl}, R_{lb}^{t}\right] = 0 \tag{17}$$

Where R_{lb}^{t} are our regulation instruments. Equation 17 says that regulation is uncorrelated with demand, conditional on observable characteristics. The reason behind this assumption is the following exclusion restriction: the only way through which risk-weights and capital requirements affect borrowers utility for a particular mortgage is via prices.

6 Estimation results

6.1 Demand parameters

In this section we presents the results from the estimation of the structural demand model. Table 8 shows the estimated demand parameters. We allow for heterogeneity across borrower types, by estimating the model separately for the three markets. In panel A we report the estimates from the first stage of the parameters that vary at the borrower-product level and the interaction of product characteristics with borrowers' income and age.

The fraction of branches in the postcode where the borrowers have the house has a positive effect, with a similar magnitude for all borrower types. The effect is stronger for older borrowers and weaker when for borrowers with a larger income. This heterogeneity in the effect of local branches on the choice probability is consistent with the household finance literature about financial literacy. Even if we don't have a proper measure of financial literacy, both income and age are often used as proxies (Drechsler et al., 2016). We find that a larger share of local branches have a stronger effect on the less financially literate borrowers.

We also allow the effect of prices and minimum down-payment to vary with individual characteristics. First, we find that older and richer borrowers seem to dislike less fees. For higher income people fee can be . Second, richer borrowers are more sensitive to the interest rate and to the minimum down-payment requirement. This can be due to higher income borrowers acting optimally along two margins. On the one hand, given the higher present (and expected?) income they want to borrow more, thus the larger negative effect of a minimum down-payment. On the other hand, income may capture financial sophistication and being correlated with shopping ability, thus the higher sensitivity to the interest rate.

Third, older borrowers are less sensitive to the interest rate and to the minimum downpayment. In the case of the latter, the result can be due to older borrowers having already more equity in their house, because of larger savings, and thus being less affected by the requirement. In the case of interest rate, the lower sensitivity of older borrowers can be attributable both to less incentives to shop around (e.g due to the lower balance of the mortgage) and to less ability to shop around (e.g. financial sophistication, access to internet).

In panel B of 8 we show the second stage estimates from of equation 14. In this way we recover the effect of the observable product characteristics on the mean value for the product at the market level. We presents both the ols and the instrumental variable estimates. Our main parameter of interest is the elasticity with respect to the interest rate (α_r). In the ols specification we find that remortgagers have the largest sensitivity to the interest rate, followed by home mover, while first time buyers are the least sensitive to the interest rate. In the case of remortgagers, there is no choice of the house, given that the borrower is only refinancing the mortgage on the existing property. For home movers and first time buyers, instead, the choice of the mortgage is linked to the choice of a new house, which can make the shopping decision more complex. Moreover, in the case of first time buyers there is no equity to extract from an existing property, which can further limit the available liquidity.

Interestingly, first time buyers are on average more sensitive to larger fees than remortgagers and home movers. Heterogeneity in the sensitivity to the interest rates and fees across borrower types can important to evaluate the effect of alternative policies.

As expected the minimum downpayment requirements have a stronger effect on first time buyers, while almost no effect on remortgagers. This corroborate again the hypothesis that for first time buyers products with a larger downpayment requirements are less attractive and affordable.

We also look at the preference for an additional product characteristics, the length of the fix period, which plays a central role in the mortgage choice (Campbell et al., 2003; Badarinza et al., 2014). In the UK mortgage market the vast majority of the product has an interest rate fixed for a period of two years, and there are really few product with a fixed rate for more than five years. We can still explore the preference to for a longer duration by comparing mortgages fixed for two versus five years. First time buyers and home movers prefers to shorter fixed rate contract, while remortgagers favour longer fixed rate mortgages. These heterogeneity can be explained by more uncertainty in the case of younger home movers and first time buyers, relative to a more certain future for remortgagers.

In the IV columns we report the estimates of the model in which we instrument interest rates with the exogenous supply side shifters describe in section 5.3. The first stage is strong with an F statistics well above then for all borrowers types. The sensitivity of demand with respect to the interest rate increase as expected.

In table 9 we report the elasticities for a specific market and different subgroups of products. The upper panel shows the ten most popular products in the market. We define the elasticity as the change in the market share as a results of an increase in the interest rate by 10 basis point. An increase by about 10 basis point decrease the market share of that product by about 6%. Moreover, the share of the other mortgage products increase by about 0.10%.

Given that our product definition combine different horizontal elements of differentiation we can compute the elasticities at various levels. In the middle panel of figure 9 we study elasticity at the loan-to-value band level. We look at the decrease in the market share of a specific loan-to-value band, when all products in that band increase experience an increase in the rate by 10 basis point. This is interesting if we consider a policy that to reduce high risky lending increase the capital requirement for all lenders in a specific loan-to-value band. We find that an increase in the interest rate by 10 basis point for all products in a loan-to-value band decrease the share of that loan-to-value band by about 5%. We can also look at the substitution toward higher or lower leverage. The closer substitute are mortgages in loan-to-value bands just above and below the affected band. The shares of the latter increase by between 0.3% and 1.6%. The market share of loan-to-value mortgages two step away increase as expected to a lesser extent, ranging from 0.6% to 1%.

In the lower panel of table 9 we look at the substitution patterns across lender types.

We consider the elasticity in the case of an increase in the price by 10 basis point for all lenders in a specific segment. A similar situation resemble sectoral specific increase in capital requirements, for example to systemically important lenders. We find that an increase in the price of all products of the big six lenders decrease their market share by approximately 0.60% with building societies increasing by 6% and challengers banks by almost 4%. The limited own-price elasticity for the big six is due to their large market share and brand value. As a result of an increase in their prices by 10 basis point, challengers banks and building society will loose 6% of their market share.

In figure 8 we show the results from the estimation of the loan demand (equation 15). We find that on average first-time-buyer have an average elasticity around 2%, and it is stable over leverage levels, with the exception of mortgages with an LTV above 90%, which have an elasticity that is not statistically different from zero. Home movers have on average a larger elasticities at around 2.5%, that is also stable across LTV. Remortgagers have the highes elasticity of loan demand, at about 5%. This elasticity decreases monotonically with LTV until 85%.

6.2 Supply parameters and impact of capital regulation

In this section we show the results of the estimation of the cost. First, in table 10 we show the estimated costs and mark-ups. We present both the baseline cost and markups from the standard mark-up pricing formula and a version, which take advantage of the additional information about mortgage performances at the product level.

In the upper panel of table 10 we show the estimated costs as a percentage of the initial interest rate. The baseline cost is about 84% of the price. Adding the refinancing risk increase the cost by about 10% of the price. This is because the marginal cost has to be paid now until maturity of the loan. Adding the default risk increase the cost on average by about 1% of the price. As already mentioned in the section 2.2.3, arrears are on average low in the UK mortgage market.The full cost as a result is almost 97% of the interest rate.

In the lower panel of table 10 we show the estimated markups, as a percentage of the initial interest rate.

Table 11 show the structural supply parameters from model 16. We presents the estimates separately for different borrower types, to allow for heterogeneity in the effect of risk weights. We show both the ols estimates and a difference in difference estimation strategy, that only exploit the joint variation across lenders and loan-to-value bands.

Out main parameter of interest is the impact of risk weights on the marginal cost of lending. We find that a 1 percentage point higher risk weights increase the cost of lending to first time buyers by about 1% for both first time buyers and home movers.

The other parameters of the cost function are also of interest. As expected a larger down-payment reduce the cost of issuing a mortgage, while a longer fix period increase it. We find that a larger dowpayment decrease the cost by twice as much for a first time buyer, than for a remortgagers.

7 Counterfactuals

In this section we study the impact of risk-based capital regulation on the equilibrium in the mortgage market. To illustrate the mechanism consider two identical products j (e.g. fixed for two years) with the same maximum loan-to-value b and with the same fees (equal to zero). They are offered by two different lenders paying the same spread and with the same fraction of outstanding borrowers paying the higher reset rate (also equal to zero). The two lenders have different regulatory risk-weights. For example the case in which one incumbent lender adopts an internal rating based model (IRB) and the challenger lender is on the standardized approach (SA). If the two mortgages have the same probability of default, the difference in prices between these two banks will be given by:

$$r_{SA} - r_{IRB} = \underbrace{\frac{rw_{SA} - rw_{IRB}}{s}}_{\text{Regulatory advantage}} - \underbrace{\frac{1}{\frac{\partial q_{SA}}{\partial r_{SA}} \frac{1}{q_{SA}}} - \frac{1}{\frac{\partial q_{IRB}}{\partial r_{IRB}} \frac{1}{q_{IRB}}}}_{\text{Incumbent advantage}} \tag{18}$$

The higher risk weights on the SA lenders translate into higher prices, coeteris paribus.

The differences in risk weights can translate into differential pricing and potential specialization in certain segments, as shown in Benetton et al. (2016). Moreover if the elasticity of the product offered by the IRB lenders is lower, due to brand power, there is also an incumbent advantage, which further amplifies the price gap.

We explore the consequences of changes the way lenders compute their risk weights on prices and market share. Table 12 shows the results. First, we simulate an equilibrium without internal models for the calculation of the capital requirements. We find that eliminating internal models increase the cost for banks adopting them, which are passed on to borrowers, via higher initial rates. However, challengers lenders and building society gain market shares and . Moreover, the less risk-sensitive standardized approach lead to an increase in the share of high loan-to-value mortgages.

Second, we allow lenders adopting a standardized approach to develop an internal model, with the capital requirements of the average IRB lender. In this case costs are lower and prices go down. The effect is stronger on the challengers lenders and even more on building societies, which do not suffer from the larger cost due to higher capital requirements. However, the more risk-sensitive approach which is now affecting all lenders lead to a decrease in the share of high loan-to-value mortgages, which limit the welfare gain from lower prices, especially for first-time-buyers.

8 Conclusion

We have developed and estimated a tractable model of the UK mortgage market that can account for several features characterizing borrowers' demand and lenders' competition. We show that the abolition of internal models will increase the overall cost of the system, both in terms of capital and risk, tilting toward high leverage products. However, the comparative disadvantage of challenger banks and building societies will be reduced and the welfare cost for highly leveraged first time buyers will be modest. The comparative disadvantage would be also eliminated by a decrease in the capital requirements at low loan-to-value for competitor lenders, with an overall decrease in prices. The gain from lower prices will be minimal for borrowers with limited equity. A full evaluation of this alternative approach would require competitor lenders to build in the cost of developing an internal model.

Our model and counterfactual simulations can have important implications for policy, especially regarding the interplay between macro-prudential regulation and competition. On the one hand, optimal macro-prudential policy design should consider the impact on the transmission mechanism to the real economy of mortgage market characteristics, such as competition and households' choices. On the other hand, regulation of the financial sector should take into account potential trade-offs between financial stability and consumer welfare.

Our paper can be extended in several directions. On the demand side, a natural next step will be to consider the housing choice jointly with the mortgage choice. One key margin of adjustment for the borrower is given by the option to rent, which will not require the mortgage choice, and postpone the decision to buy a house. This will complicate the model, by adding an important dimension related to the timing of the decision, and would require data on borrower that bought a house with a mortgage together with households that *choose* to rent. On the supply side, the lenders decision can be enlarged to include the acceptance/rejection margin. So far, we have captured it in a reduce form way through affordability constraints and macro-prudential regulation affecting interest rates. A more realistic model will include an explicit decision from the lender to issue a mortgage to a specific borrower.

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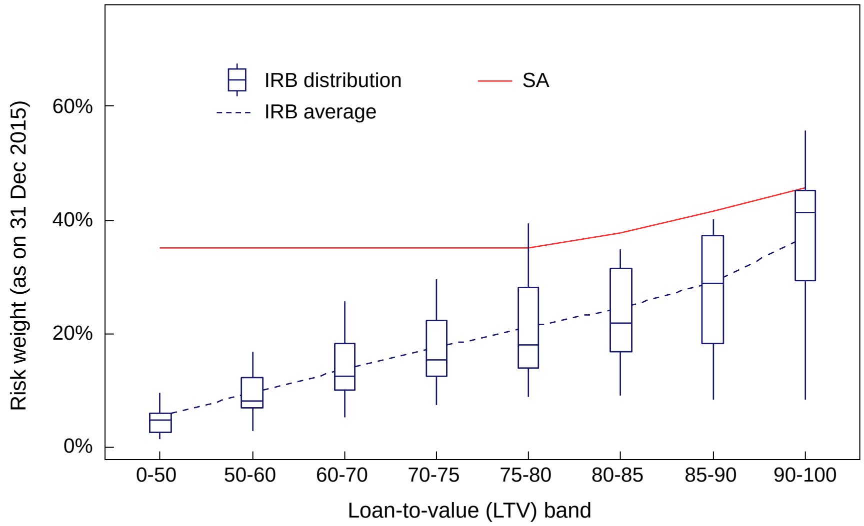
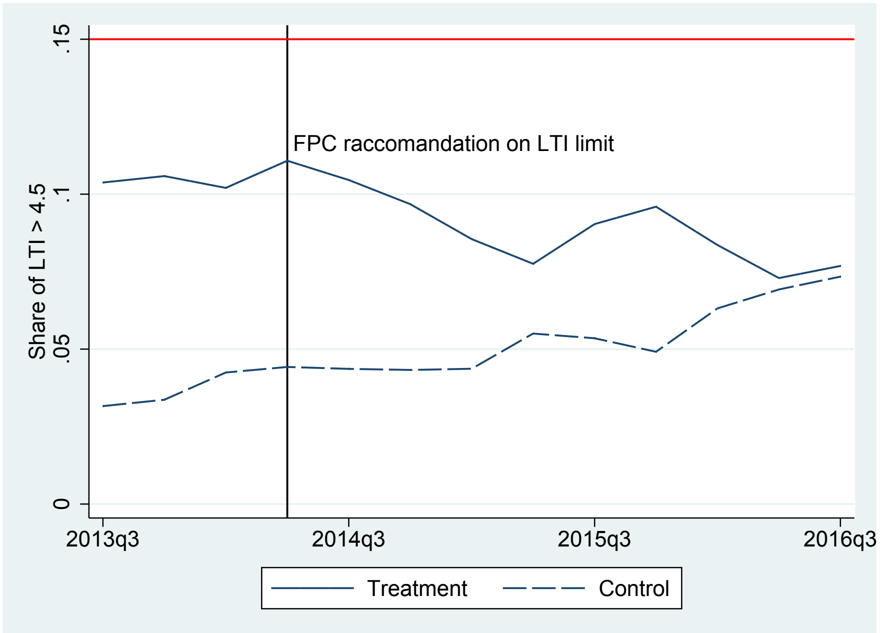
Appendix: Charts

Figure 1: Risk-weights across lenders and leverage bands



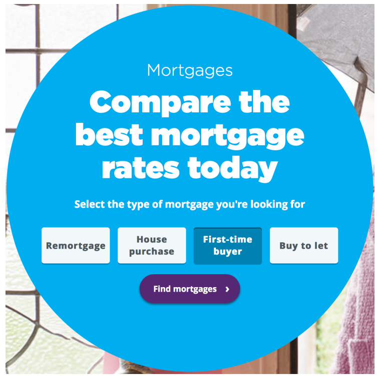
Notes: the chart shows the average risk weight for two groups of lenders at different loan-to-value bands. IRB includes all lenders in the sample adopting and internal rating base model for the calculation of the capital requirements. SA includes all lenders that adopt the standardized approach. For the latter group the risk weights are set by the regulator accoding to a fixed formula. Source: Prudential Regulation Authority.

Figure 2: Reccomendation on LTI limits



Notes: the chart shows the percentage of mortgages with a loan-to-income (LTI) above 4.5 for two groups of lenders in each quarter. Treatment include lenders with an average share of LTI above 4.5 higher than the median in the year before June 2014. Source: Financial Conduct Authority Product Sales Database.

Figure 3: Choice-set



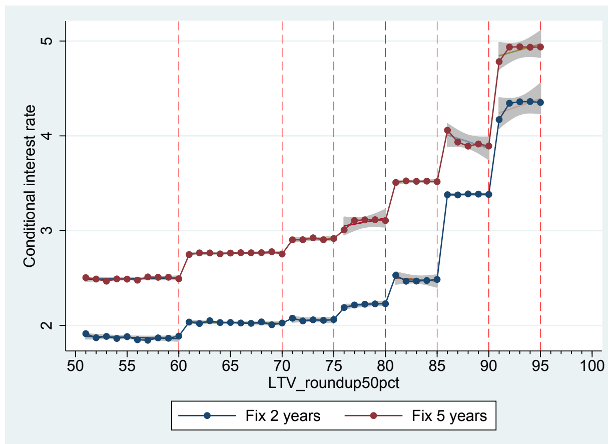
(a) Borrower type

Provider	Initial monthly cost	Initial rate	Type of mortgage	Max LTV	Product fees	Overall cost for comparison
HSBC	£ 635.05	1.99% then 3.94%	Fixed for 25 months	90%	Yes	3.8% APRC representative
The Loughborough Building Society	£ 639.44	2.05% then 4.99%	Discounted Variable for 24 months	90%	Yes	4.6% APRC representative
Yorkshire Building Society	£ 641.64	2.08% then 4.99%	Fixed for 25 months	90%	Yes	4.7% APRC representative
Yorkshire Building Society	£ 641.64	2.08% then 4.99%	Fixed for 25 months	90%	Yes	4.7% APRC representative
Leek United Building Society	£ 642.37	2.09% then 5.19%	Fixed for 27 months	90%	Yes	4.7% APRC representative
first direct	£ 646.05	2.14% then 3.69%	Fixed for 24 months	90%	Yes	3.6% APRC representative

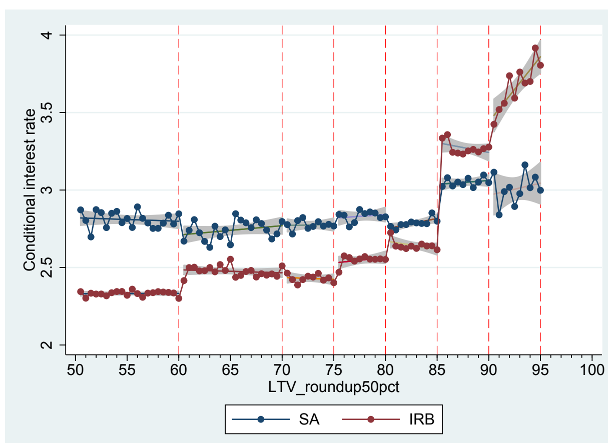
(b) Products

Notes: the upper panel shows the first snapshot from a search of mortgages in a popular website. The lower panel shows the second snapshot after filling some information in the above panel. Source: Moneysupermarket

Figure 4: Pricing: step-wise schedule with leverage



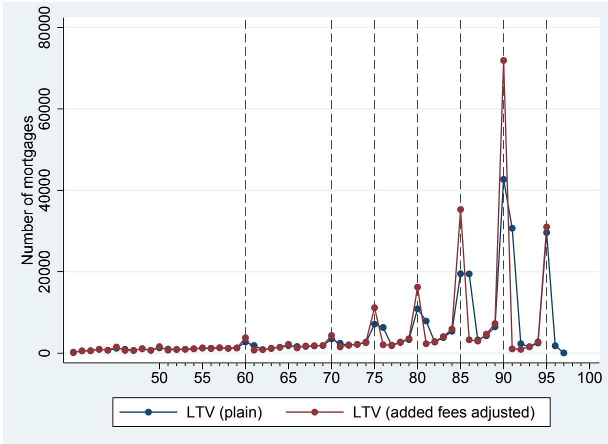
(a) Different dealtype



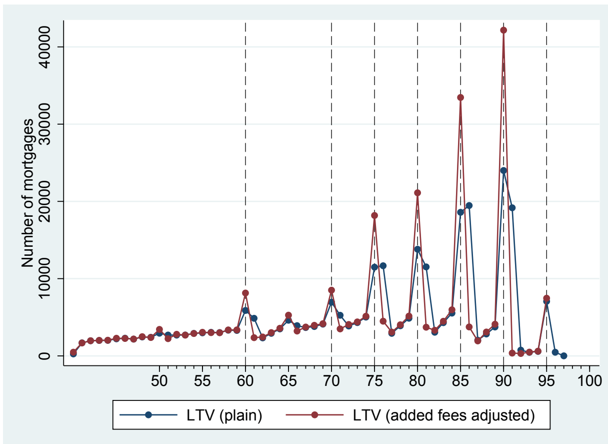
(b) Different lenders

Notes: the charts show the conditional interest rate from the following regression: $r_{jlb}^{kt} = \gamma_{jl}^{kt} + \sum_{j=50}^{95} ltv_j$, where γ_{jl}^{kt} are fixed effects for market, type and lenders and ltv_j are loan-to-value bins. The upper panel shows the schedule for the two most popular products: fixed rate mortgage for 2 and 5 years. The lower panel shows the schedule for representative lenders adopting the internal model and the standardized approach. Source: Financial Conduct Authority Product Sales Database.

Figure 5: Origination: leverage



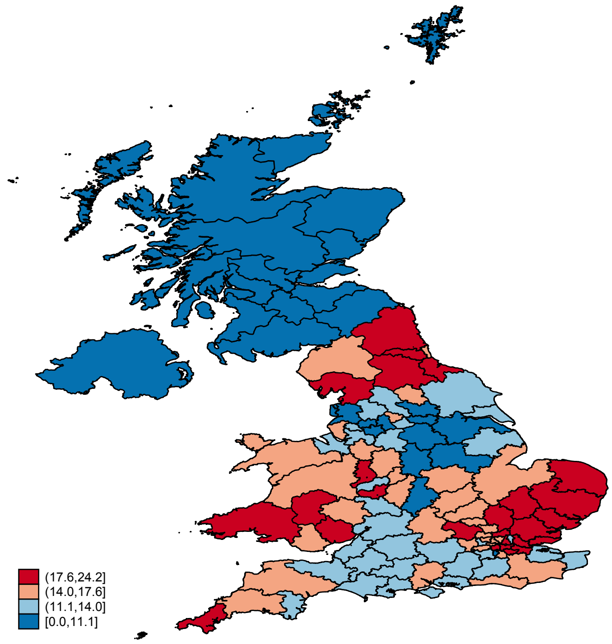
(a) First time buyers



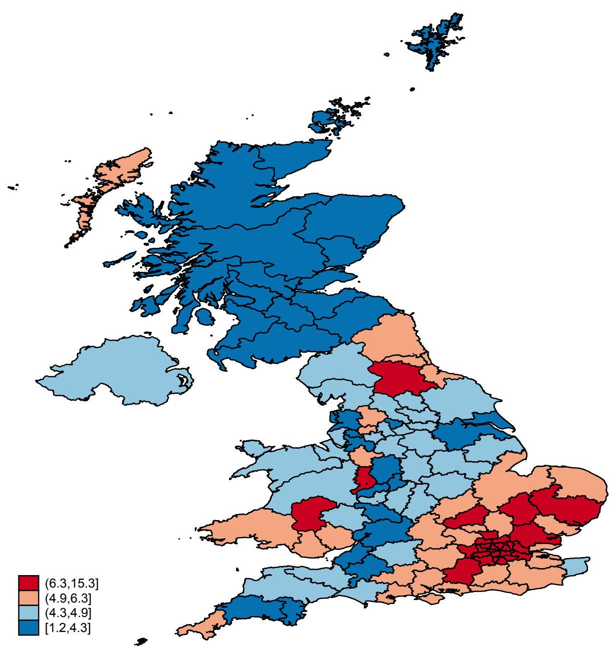
(b) Home movers

Notes: the charts show the share of mortgages originated at different loan-to-value bins. The upper panel shows originations for first-time-buyers, while the lower panel shows originations for home-movers. Source: Financial Conduct Authority Product Sales Database.

Figure 6: Origination: market shares in different areas



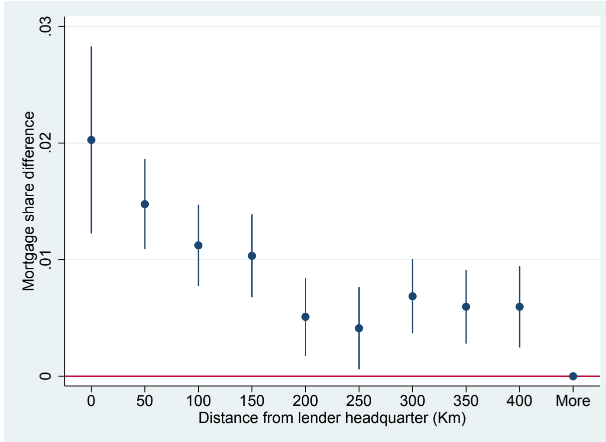
(a) Branches



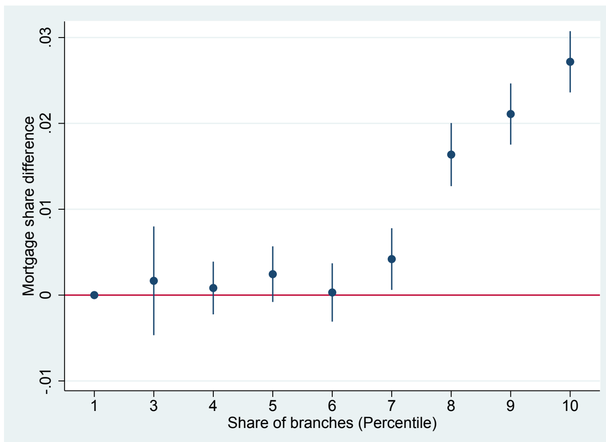
(b) Mortgages

Notes: the upper panel shows the market share of all branches for a lender in the sample by geographical area. The lower panel show the market share of the same lender for mortgage originations. Source: Financial Conduct Authority Product Sales Database; SNL financial.

Figure 7: Origination: Distance and branches



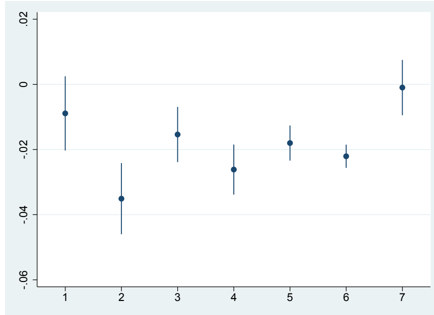
(a) Distance and market-shares



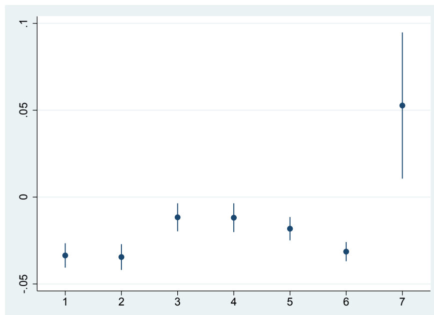
(b) Branches and market-shares

Notes: the upper panel shows the coefficients β from the following difference in difference specification: $share_{la} = \gamma_l + \gamma_a + \sum_{k=1}^{10} \beta^k distance_{la}^k$, where γ_l and γ_a are lender and area (postcode) fixed effects and $distance_k$ are 50 km bins for distance between the house and the lender headquarter. The lower panel the coefficients β from the following difference in difference specification: $share_{la} = \gamma_l + \gamma_a + \sum_{k=1}^{10} \beta^k branch_{la}^k$, where γ_l and γ_a are lender and area (postcode) fixed effects and $branch_k$ are decile of the branch share distribution. Source: Financial Conduct Authority Product Sales Database.

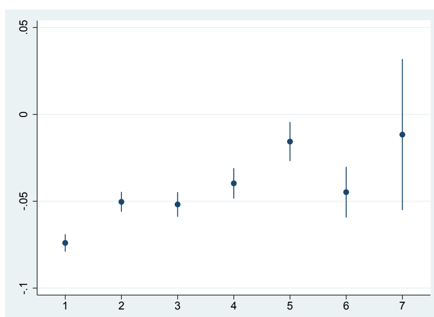
Figure 8: STRUCTURAL DEMAND ESTIMATES: LOAN DEMAND



(a) FIRST TIME BUYERS



(b) HOME MOVERS



(c) REMORTGAGERS

Notes: the charts show the elasticity of loan size demand at different loan-to-value bins. The upper panel shows the coefficients for first-time-buyers, the middle panel for home-movers and the lower panel for remortgagers.

Appendix: Tables

Table 1: FACTS: PRICING IN THE MORTGAGE SUPERMARKET

	RATE					FEES				
	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
PRODUCT	Yes	No	No	No	No	Yes	No	No	No	No
PRODUCT-MARKET	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
FEES-INTEREST	No	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes
POSTCODE	No	No	No	Yes	No	No	No	No	Yes	No
CONTROLS	No	No	No	No	Yes	No	No	No	No	Yes
R^2	0.78	0.85	0.91	0.91	0.91	0.23	0.40	0.67	0.71	0.72
OBSERVATIONS	569406	569403	569107	569107	569107	569406	569403	569390	569390	569390

Notes: the table reports the R^2 of regressions of borrower level interest rates and fees (r_{jlb}^{ikt} and f_{jlb}^{ikt}) on a set of dummy variables. Column (1) includes only dummy for the product, defined by the interaction of mortgage type, lender and loan-to-value band. Column (2) adds dummies for the market, defined by borrower type and month. Column (3) adds dummies for the other price, fee when rate is the dependent variable and viceversa. Column (4) adds dummies for the location of the house of the borrower and column (5) includes borrower level controls (e.g. income, age). Source: Financial Conduct Authority Product Sales Database.

Table 2: Facts: Pricing decomposition

	Rate							Fees						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Product	Yes	No	No	No	No	No	No	Yes	No	No	No	No	No	No
Type	No	Yes	No	No	No	No	No	No	Yes	No	No	No	No	No
Lender	No	No	Yes	No	No	No	No	No	No	Yes	No	No	No	No
Band	No	No	No	Yes	No	No	No	No	No	No	Yes	No	No	No
Market	No	No	No	No	Yes	No	No	No	No	No	No	Yes	No	No
Borr. Type	No	No	No	No	No	Yes	No	No	No	No	No	No	Yes	No
Time	No	No	No	No	No	No	Yes	No	No	No	No	No	No	Yes
R^2	0.87	0.20	0.08	0.61	0.17	0.14	0.03	0.43	0.02	0.29	0.00	0.07	0.04	0.03
Observations	5019	5019	5019	5019	5019	5019	5019	5019	5019	5019	5019	5019	5019	5019
Markets	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Products	153	153	153	153	153	153	153	153	153	153	153	153	153	153

Notes: the table reports the R^2 of regressions of interest rates and fees (r_{jlb}^{kt} and f_{jlb}^{kt}) on a set of dummy variables. Column (1) includes only dummy for the product, defined by the interaction of mortgage type, lender and loan-to-value band. Column (2) to (4) decompose the effect of the product dummies into mortgage type (2), lender (3) and loan-to-value band (4). Column (5) includes dummies for the market, defined by borrower type and month. Column (6) to (7) decompose the effect of the market dummies into borrower type (6) and time (7). Source: Financial Conduct Authority Product Sales Database.

Table 3: Facts: Originations

	First time buyer			Home movers			Remortgagers		
	Share	Rate	Fee	Share	Rate	Fee	Share	Rate	Fee
Full sample	87.6	3.1	615.0	78.8	2.5	914.0	79.6	2.3	234.0
Type									
Fix 2 years	64.5	3.0	595.0	55.6	2.4	868.0	51.7	2.0	225.0
Fix 5 years	23.1	3.3	620.0	23.1	2.8	995.0	27.9	2.7	234.0
Lender									
Big six	70.0	3.1	679.0	59.2	2.5	995.0	56.7	2.3	30.0
Challenger	7.1	3.3	545.0	7.8	2.7	615.0	9.3	2.3	195.0
Building society	8.2	2.9	554.0	9.4	2.5	800.0	10.7	2.1	433.0
Band									
40-60	2.3	3.3	604.0	2.3	2.9	1,009.0	3.0	2.5	380.0
60-70	7.2	2.3	659.0	14.5	2.2	875.0	27.0	2.2	235.0
70-75	5.4	2.4	770.0	9.9	2.3	995.0	17.0	2.2	349.0
75-80	6.2	2.3	770.0	9.3	2.3	995.0	12.8	2.3	433.0
80-85	8.6	2.4	795.0	10.3	2.3	995.0	10.5	2.3	99.0
85-90	17.0	2.6	704.0	14.8	2.5	995.0	8.4	2.6	30.0
90-95	30.4	3.5	643.0	17.0	3.4	800.0	3.9	3.3	173.0
90-95	12.9	4.5	163.0	3.0	4.5	278.0	0.1	3.9	286.5

Notes: the table reports the market share and average price (rate and fee) for different categories of product and borrower type. Share are expressed as a ratio of the full sample of borrowers and mortgage products. Source: Financial Conduct Authority Product Sales Database.

Table 4: Facts: Performances

	First time buyer			Home movers			Remortgagers		
	Arrears	Refinancing	SVR	Arrears	Refinancing	SVR	Arrears	Refinancing	SVR
Full sample	2.3	77.5	4.7	2.2	75.7	4.7	3.5	71.0	4.5
Lender									
Big six	1.9	72.8	4.0	1.9	70.6	4.0	3.2	67.3	4.0
Challenger	2.9	78.1	4.7	2.6	77.6	4.6	4.1	70.1	4.5
Building society	2.3	85.2	5.0	2.5	82.6	5.0	3.3	78.6	5.0
Band									
40-60	1.4	80.3	4.6	1.1	80.9	4.6	1.5	78.6	4.3
60-70	1.8	81.2	4.6	1.4	81.5	4.6	2.1	78.8	4.2
70-75	1.3	83.7	4.7	1.4	81.1	4.6	2.3	78.1	4.0
75-80	1.6	85.0	4.7	1.4	81.6	4.6	2.4	77.7	4.0
80-85	1.2	83.8	4.6	1.5	79.8	4.6	3.1	74.0	4.5
85-90	1.7	79.3	4.7	2.0	74.0	4.6	5.0	63.1	4.5
90-95	3.0	76.0	4.5	3.2	72.1	4.6	6.2	57.8	4.5

Notes: the table reports the fraction of mortgages in arrears, the fraction of borrowers paying the standard variable rate and the median standard variable rate for different categories of product and borrower type. Source: Financial Conduct Authority Product Sales Database.

Table 5: Competition and capital regulation

	Cost: Risk-weights		Price: Rate		Quantity: Portfolio shares		Quantity: Market shares	
	Low LTV	High LTV	Low LTV	High LTV	Low LTV	High LTV	Low LTV	High LTV
Market	13.6	23.5	2.3	3.1	49.6	52.1	48.7	51.3
Competition								
Leader	19.0	29.7	2.2	3.1	59.6	40.4	8.7	5.6
Challenger	17.7	35.8	2.2	3.1	46.3	53.7	2.9	3.2
Capital regulation								
Lowest IRB	7.5	10.1	2.3	3.3	47.1	52.9	13.3	14.1
Highest IRB	14.5	32.2	2.2	3.1	46.6	53.4	11.6	12.6
SA	35.0	40.2	2.5	3.4	37.0	63.0	0.9	1.4

Notes: the table shows cost, price and quantity at the market level and for different representative lenders in the sample at different loan-to-value bands. Low ltv includes all mortgages with a loan-to-value below 75%. Cost is given by the risk weights on the capital requirement. Price is the initial interest rate on mortgage originations. Quantity is portfolio and market shares. Market are averages across the whole markets. Leaders and challengers are averages across lenders. Lowest IRB, highest IRB and SA are averages across lenders with the lowest risk weights, the highest and the standardized approach. Source: Financial Conduct Authority Product Sales Database, Authors calculation.

Table 6: REDUCE FORM EVIDENCE ON THE IMPACT OF CAPITAL REQUIREMENTS

DEPENDENT VARIABLE:	WHOLE SAMPLE		BORROWER TYPE		
INTEREST RATE r^{kt}_{jlb}	(1)	(2)	(FTB)	(HM)	(RMGT)
CAP REQ (%)	0.088***	0.070***	0.250***	0.160***	-0.007
	(0.006)	(0.011)	(0.022)	(0.025)	(0.011)
FIX 5		0.782***	0.785***	0.840***	0.742***
		(0.012)	(0.023)	(0.021)	(0.015)
MIN DOWN (%)		-0.047***	-0.052***	-0.042***	-0.031***
		(0.001)	(0.002)	(0.002)	(0.001)
TIME F.E.	Yes	Yes	Yes	Yes	Yes
BORR TYPE F.E.	Yes	Yes	Yes	Yes	Yes
LENDER F.E.	No	Yes	Yes	Yes	Yes
R^2	0.21	0.74	0.76	0.74	0.75
OBSERVATIONS	5019	5019	1620	1737	1662

Notes: The table reports the estimate of the impact of risk-weighted capital requirements on lending, from the following specification: $r^{kt}_{jlb} = \beta CapReq^t_{lb} + X_{jlb} + \gamma^{kt} + \gamma_l + \epsilon^{kt}_{jlb}$. r^{kt}_{jlb} is the interest rate in month t for borrower type k offered by lender l for product j at LTV band b; $CapReq^t_{lb}$ is the risk-adjusted capital requirement; X_{jlb} are product level controls (Fix 5 is a dummy for product with a fixed period of five years, $Mindown$ is the minimum downpayment for the product); γ^{kt} and γ_l are borrower type, time and lender fixed effects. Source: Financial Conduct Authority Product Sales Database, Authors calculation.

Table 7: Reduce form evidence on the impact of LTI limits

Dependent variable:	Whole sample		Borrower type		
share of LTI > 4.5	(1)	(2)	(FTB)	(HM)	(RMGT)
Treatment	0.066***				
	(0.011)				
Post	0.017**				
	(0.007)				
Treatment × Post	-0.038***	-0.038**	-0.074**	-0.024*	-0.015
	(0.011)	(0.013)	(0.026)	(0.012)	(0.009)
Time F.e.	No	Yes	Yes	Yes	Yes
Lender F.e.	No	Yes	Yes	Yes	Yes
R^2	0.19	0.38	0.49	0.74	0.78
Observations	702	702	234	234	234

Notes: The table looks at the impact of the loan-to-income (LTI) reccomendation introduced in June 2014 on the amount of lending at high LTI. The dependent variable is the share of LTI above 4.5 in lenders' portfolio share. Source: Financial Conduct Authority Product Sales Database, Authors calculation.

Table 8: STRUCTURAL DEMAND ESTIMATES: PRODUCT CHOICE

	FTB		HM		RMGT	
PANEL A: FIRST STAGE						
BRANCHES	0.37		0.38		0.36	
	(0.06)		(0.04)		(0.03)	
BRANCHES × OLD	0.08		0.05		0.13	
	(0.03)		(0.02)		(0.03)	
BRANCHES × RICH	-0.15		-0.14		-0.14	
	(0.03)		(0.04)		(0.03)	
FEE × OLD	0.02		-0.00		0.03	
	(0.01)		(0.00)		(0.01)	
FEE × RICH	0.01		0.01		0.02	
	(0.03)		(0.02)		(0.02)	
RATE × OLD	-0.05		0.02		0.26	
	(0.05)		(0.07)		(0.07)	
RATE × RICH	-0.26		-0.19		-0.31	
	(0.04)		(0.05)		(0.09)	
MIN DOWN × OLD	0.01		0.03		0.04	
	(0.00)		(0.00)		(0.00)	
MIN DOWN × RICH	-0.03		-0.02		-0.01	
	(0.00)		(0.00)		(0.00)	
PANEL B: SECOND STAGE						
	(OLS)	(IV)	(OLS)	(IV)	(OLS)	(IV)
RATE(%)	-0.12*	-0.68**	-0.16***	-0.68**	-0.29***	-2.00***
	(0.07)	(0.31)	(0.06)	(0.32)	(0.08)	(0.67)
FEE (LOG)	-0.10***	-0.12***	0.00	-0.02	-0.07***	-0.15***
	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.04)
MIN DOWN	-0.03***	-0.07***	-0.02***	-0.05***	-0.00	-0.05***
	(0.00)	(0.02)	(0.00)	(0.02)	(0.00)	(0.02)
FIX 5	-0.55***	-0.11	-0.32***	0.13	0.12*	1.45***
	(0.07)	(0.24)	(0.06)	(0.27)	(0.07)	(0.51)
MARKET FE.	Yes	Yes	Yes	Yes	Yes	Yes
LENDER TYPE FE.	Yes	Yes	Yes	Yes	Yes	Yes
R2	0.37	0.31	0.33	0.26	0.33	-0.00
OBSERVATIONS	1403	1403	1456	1456	1427	1427
F EXCLUDED		18.49		17.03		17.56

Notes: the table shows the structural paramters of the mortgage demand model. In panel A we report the coefficients of the first stage. In panel B we show the coefficients of the second stage. We report both the ols and the iv model. Standard errors in the first stage are clustered at the borrower level. Standard errors with 50 bootstrap replications in the second stage. The excluded instruments in the calculation of the F statistic are the lender time-varying capital requirements and the product specific risk weights.

Table 9: Elasticities

	1	2	3	4	5	6	7	8	9	10
1	-6.33	0.10	0.05	0.14	0.13	0.12	0.12	0.10	0.17	0.00
2	0.17	-6.34	0.00	0.14	0.13	0.11	0.12	0.10	0.17	0.00
3	0.07	0.00	-6.33	0.12	0.05	0.10	0.05	0.08	0.07	0.27
4	0.12	0.07	0.07	-6.33	0.10	0.13	0.09	0.11	0.13	0.09
5	0.16	0.10	0.05	0.14	-6.35	0.12	0.12	0.10	0.17	0.00
6	0.12	0.07	0.07	0.16	0.10	-6.35	0.09	0.11	0.13	0.09
7	0.16	0.10	0.05	0.14	0.13	0.12	-6.37	0.10	0.17	0.00
8	0.13	0.07	0.07	0.16	0.10	0.13	0.09	-6.37	0.13	0.09
9	0.16	0.10	0.05	0.14	0.13	0.12	0.12	0.10	-6.32	0.00
10	0.00	0.00	0.11	0.06	0.00	0.05	0.00	0.04	0.00	-6.01

(a) Top 10 products

	40-60	60-70	70-75	75-80	80-85	85-90	90-95
40-60	-6.08	0.69	0.58	0.00	0.00	0.00	0.00
60-70	0.35	-5.93	0.76	0.30	0.00	0.00	0.00
70-75	0.13	0.34	-5.32	0.69	0.43	0.00	0.00
75-80	0.00	0.13	0.65	-5.58	0.83	0.64	0.00
80-85	0.00	0.00	0.22	0.45	-5.41	1.22	0.27
85-90	0.00	0.00	0.00	0.29	1.03	-5.00	0.37
90-95	0.00	0.00	0.00	0.00	1.00	1.62	-5.96

(b) Loan-to-value bands

	Big six	Challenger	Building society
Big six	-0.60	0.27	0.30
Challenger	5.90	-6.02	0.42
Building society	6.01	0.39	-6.09

(c) Lenders

Notes: The tables report the elasticities from a market for first-time-buyers. In the upper panel we report the elasticies for the top ten products in terms of market shares. Elasticities are interpreted as the percentage change in market share in reponse to a 10 bp increase in the initial interest rate. In the middle panel we report the elasticity at the loan-to-value band level. Elasticities in the middle panel are computed as the change in the market share of a certain loan-to-value band when the interest rate of all products in that loan-to-value band increase by 10 bp. In the bottom panel we show the elasticities at the lender type level. Elasticities in the bottom panel are computed as the change in the market share of all lenders of a certain type when the interest rate of all products offered by lenders of that type increase by 10 bp.

Table 10: Costs and mark-ups

	mean	sd	p10	p50	p90
40<ltv≤75					
Baseline	80.5	5.4	74.5	80.8	87.0
Refinancing risk	89.9	6.9	78.5	90.6	100.0
Default risk	81.3	5.5	75.0	82.4	87.7
Full	90.9	7.3	78.9	91.1	101.5
75<ltv≤85					
Baseline	84.4	3.4	79.9	84.5	88.0
Refinancing risk	93.4	8.0	85.3	92.4	104.1
Default risk	85.3	3.4	80.3	85.5	89.1
Full	94.3	8.2	85.7	93.4	104.5
85<ltv≤95					
Baseline	88.4	1.7	86.7	89.1	90.4
Refinancing risk	102.6	14.5	89.1	99.0	121.3
Default risk	89.8	2.2	87.7	89.9	91.9
Full	104.2	15.0	89.7	103.2	124.5
All					
Baseline	84.5	4.9	75.4	86.1	89.6
Refinancing risk	95.4	11.6	85.3	93.0	108.4
Default risk	85.5	5.2	76.6	86.6	91.1
Full	96.6	12.1	85.6	94.0	110.3

	mean	sd	p10	p50	p90
Big six					
Baseline	83.9	5.3	75.3	84.8	89.5
Refinancing risk	95.8	12.1	82.8	93.5	111.8
Default risk	84.8	5.4	76.5	86.1	91.0
Full	96.8	12.5	83.3	94.8	113.1
Challengers					
Baseline	88.1	1.8	85.4	87.7	90.4
Refinancing risk	100.9	12.6	85.5	99.0	127.2
Default risk	89.5	2.2	85.5	89.9	91.7
Full	102.5	13.3	85.6	104.1	129.8
Building societies					
Baseline	85.4	3.3	81.1	86.1	89.3
Refinancing risk	89.6	4.4	84.0	89.1	94.8
Default risk	86.8	4.0	82.4	87.7	90.0
Full	91.1	5.6	85.6	89.8	97.6
All					
Baseline	84.5	4.9	75.4	86.1	89.6
Refinancing risk	95.4	11.6	85.3	93.0	108.4
Default risk	85.5	5.2	76.6	86.6	91.1
Full	96.6	12.1	85.6	94.0	110.3

(a) Costs

	mean	sd	p10	p50	p90
40<ltv≤75					
Baseline	19.5	5.4	13.0	19.2	25.5
Full	41.0	25.9	14.7	26.2	87.0
75<ltv≤85					
Baseline	15.6	3.4	12.0	15.5	20.1
Full	30.3	16.9	15.9	23.8	53.7
85<ltv≤95					
Baseline	11.6	1.7	9.6	10.9	13.3
Full	26.0	13.4	11.0	23.0	45.4
All					
Baseline	15.5	4.9	10.4	13.9	24.6
Full	32.3	20.1	13.9	25.2	59.3

	mean	sd	p10	p50	p90
Big six					
Baseline	16.1	5.3	10.5	15.2	24.7
Full	35.1	22.0	13.7	25.2	69.3
Challengers					
Baseline	11.9	1.8	9.6	12.3	14.6
Full	24.7	9.8	9.7	28.3	37.1
Building societies					
Baseline	14.6	3.3	10.7	13.9	18.9
Full	22.6	6.2	14.3	22.8	29.6
All					
Baseline	15.5	4.9	10.4	13.9	24.6
Full	32.3	20.1	13.9	25.2	59.3

(b) Markups

Notes: The tables report the elasticities from a market for first-time-buyers. In the upper panel we show predicted cost and in the lower panel we show predicted markups. Both are expressed as a percentage of the interest rate. The baseline cost and markup do not include any additional information about performances. Remortgage risk include the fraction of borrowers that do not refinance the mortgage at the end of the initial period. Default risk include the fraction of borrowers that are in arrears. Full include both refinancing and default risk.

Table 11: Structural supply estimates

	FTB		HM		RMGT	
	(OLS)	(DD)	(OLS)	(DD)	(OLS)	(DD)
Risk weights (%)	0.01***	0.00*	0.01***	0.01***	-0.01***	-0.01**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Min down (%)	-0.06***		-0.05***		-0.03***	
	(0.00)		(0.00)		(0.00)	
Fix 5	0.80***	0.81***	0.85***	0.88***	0.73***	0.73***
	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)
Market fe.	Yes	Yes	Yes	Yes	Yes	Yes
Lender type fe.	Yes	No	Yes	No	Yes	No
Band fe.	No	Yes	No	Yes	No	Yes
Lender fe.	No	Yes	No	Yes	No	Yes
R2	0.75	0.90	0.72	0.89	0.74	0.82
Observations	1403	1403	1456	1456	1427	1427

Notes: the table shows the structural paramters of the supply model.

Table 12: Counterfactual risk-adjusted capital requirements

	True:		Benchmark:			Counterfactuals:					
						No internal models			Average internal model		
	Rates	Shares	Costs	Rates	Shares	Δ Costs	Δ Rates	Δ Shares	Δ Costs	Δ Rates	Δ Shares
Lender type											
Big six	3.3	61.5	1.8	3.3	81.3	10.6	5.8	-1.8	0.0	-0.0	-1.1
Challenger	4.1	3.1	2.7	4.1	9.1	1.0	0.7	9.4	-2.0	-1.3	1.4
Building society	3.4	5.0	2.0	3.4	9.7	2.0	1.2	6.4	-7.5	-4.3	8.2
Leverage											
60	2.6	6.0	1.1	2.6	5.7	22.1	9.6	-0.6	0.0	-0.0	-0.1
70	2.7	4.7	1.3	2.7	9.9	18.8	8.6	-0.6	0.0	-0.0	-0.2
75	2.6	6.0	1.2	2.7	14.0	15.6	6.9	-0.6	-1.9	-0.8	-0.1
80	2.9	8.3	1.4	2.9	12.8	10.4	5.2	0.0	-2.5	-1.2	0.1
85	3.4	14.4	2.0	3.5	23.1	6.9	4.0	-1.1	-1.3	-0.8	-0.2
90	4.0	28.4	2.5	4.0	27.9	4.4	2.8	1.2	-1.4	-0.9	0.3
95	4.9	1.9	3.4	4.9	6.6	2.2	1.6	1.4	-1.5	-1.0	-0.1
Consumer surplus	-4.1					-2.3			0.5		

(a) First time buyers

Notes: the table shows the true and predicted values and two counterfactual scenarios for the interest rate, market shares and costs. In the first counterfactual scenario, we impose all lenders to adopt the standardized approach for setting the risk weights. In the second counterfactual we compute the mean risk weight across IRB lenders and simulate a scenario in which SA lenders develop and internal model that gives them the average risk weight of their IRB competitors.